Appendix F
SUBREGIONAL GROUND WATER MODELS

OVERVIEW OF SUBREGIONAL MODELING

Introduction and Purpose

The primary goals and objectives of the *Lower East Coast (LEC) Regional Water Supply Plan* include the conceptual design and evaluation of numerous structural improvements to the regional water management system within the Lower East Coast Service Areas (LECSAs), as discussed in Appendix C. In support of this objective, five high resolution ground water flow models were developed to allow the various proposed structural improvement plans to be evaluated and compared at the desired level of detail. The boundaries of these models are depicted in **Figure F-1**.

An evaluation of water supply improvements based on hydrologic models is necessarily made relative to both current and future base conditions (i.e. as is with no improvements). Additionally, the ability of hydrologic models to assess the benefits and impacts of the proposed improvements is usually realized through the systematic use of preselected performance measures. Examples of such performance measures would include, but not be limited to, stage duration curves for wetlands and reservoirs, ground water level hydrographs, and ground water flow across selected boundaries. In the evaluation of structural water supply alternatives for the *LEC Regional Water Supply Plan*, assessments of the benefits and impacts of proposed improvements were carried out by first constructing performance measure based graphics from the model output of each type of scenario simulation (i.e. current base, future base, and various future improved) and then comparing the graphics across the simulations.

Each of the subregional models developed in support of the *LEC Regional Water Supply Plan* was used to perform this type of comparative analysis of the alternatives that were proposed within the respective model domains. To aid in developing an understanding of the common model features that are required to accomplish this objective, general discussions of typical features that are common to all of the subregional models are provided below. Specific details regarding the development and unique features of each model are provided later within this appendix.

General Features of MODFLOW

Once modeling objectives have been established and a preliminary understanding of the predominant hydrologic processes within each area of interest has been attained, one of the subsequent steps that occurs early in the model development process is the selection of a model code that can meet the model development and application objectives. MODFLOW, a code created by the U.S. Geological Survey (USGS), was selected for this purpose for the following primary reasons:

- It has been widely accepted in the ground water modeling profession for over ten years
- The code is well documented and within the public domain
- The code is readily adaptable to a variety of ground water flow systems

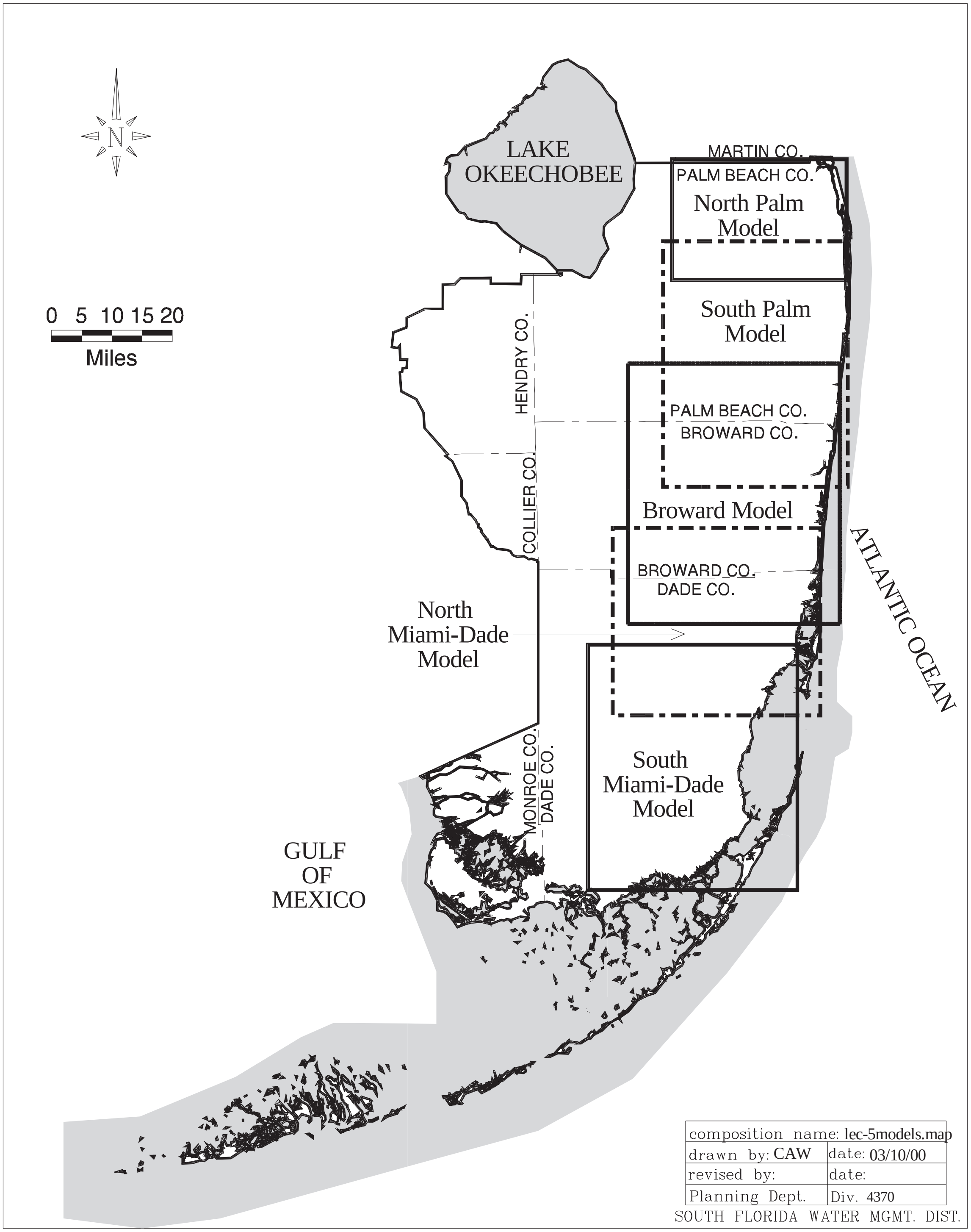

Figure F-1. Boundaries for the Lower East Coast Subregional Ground Water Models.

- The modular structure of the code facilitates any modifications required to enable its application to the types of unique ground water flow problems encountered in South Florida
- MODFLOW was used to develop existing ground water flow models located within the LECSAs that could be upgraded to meet the current objectives

MODFLOW simulates ground water flow in aquifer systems using the finite-difference method. The aquifer system is divided into rectangular or quasi-rectangular blocks by a grid (**Figure F-2**). The grid of blocks is organized by rows, columns, and layers, and each block is commonly called a cell.

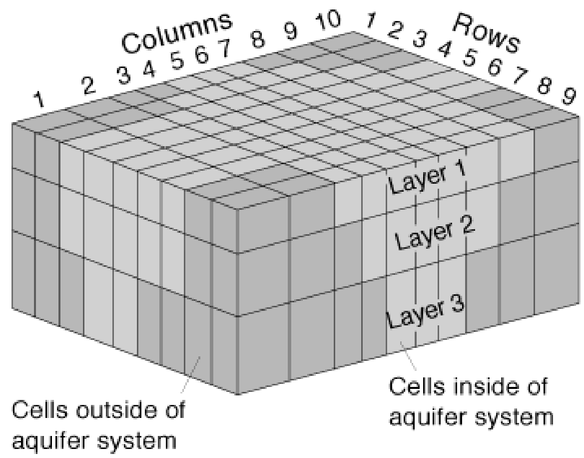

Figure F-2. Example of a Model Grid for Simulating Three-Dimensional Ground Water Flow.

For each cell within the volume of the aquifer system, the user must specify aquifer properties. Also, the user specifies information relating to wells, canals, and other hydrologic features for the cells corresponding to the locations of the features. For example, if the interaction between a canal and an aquifer system is simulated, then for each cell traversed by the canal, the required input information includes layer, row, and column indices; canal stage; and hydraulic properties of the channel bed. Also, MODFLOW allows the user to specify which cells within the grid of blocks are part of the ground water flow system and which are inactive (i.e. outside of the ground water flow system).

The MODFLOW model code consists of a main program and a series of independent subroutines called modules. The modules, in turn, have been grouped into packages which deal with a particular hydrologic process or solution algorithm. The packages used for LEC simulations, including those developed or enhanced by South Florida Water Management District (District, SFWMD) staff, are shown in **Table F-1**.

General Subregional Model Features

In addition to the application of the MODFLOW code, there are various other features that are common to each of the subregional models. Brief discussions of these features are provided below. In particular, it should be emphasized that certain types of input to these subregional models depend on the characteristics of regional water management systems and therefore need to be derived from the results of the regional model simulations (**Table F-1**). Consequently, a brief description of the relationship between the subregional models and the regional model, the South Florida Water Management Model (SFWMM), is also provided.

Table F-1. MODFLOW Packages Used in the LEC Subregional Models.

Package	Description	Notes
Core		
Basic and Output Control	Defines stress periods, time steps, starting heads, grid specifications, units, and output specifications	Handles the primary administrative tasks associated with a simulation
Block-Centered Flow	Specifies steady state vs. transient flag, cell sizes, anisotropy, layer types, and hydrogeologic data for each layer	Derived primarily from geologic data used to construct the model
Surface Water Stresses and Processes		
Recharge	Simulates aerially distributed recharge to a water table during each stress period	Preprocessed using an Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) based ET-Recharge model
Evapotranspiration (ET)	Simulates removal of water from the water table via transpiration and direct evaporation	Preprocessed using an AFSIRS based ET-Recharge model; ET rate diminishes with increasing water table depth
River	Simulates ground water interchanges with canals that can either recharge or drain the aquifer	Canal stages are usually based on measured stages, control elevations, or stages extracted from South Florida Water Management Model (SFWMM) output
Drain	Essentially the same as the River package except that canals can only drain the aquifer and water removed by the drains is removed permanently from the model	Canal stages are usually based on measured stages, control elevations, or stages extracted from SFWMM output
Canal	Essentially the same as the River package except it adds the capabilities to limit the drainage rate to a specific rate and the recharge rates to a different rate, as well as allowsing separate control levels for recharge and drainage	When applied in combination with the wetlands package the controlled discharge is the combined total of surface water runoff and ground water seepage. When applied without the Wetlands package, the controlled discharge is the solely groundwater seepage.
Redirected Flow	Essentially the same as the Drain package except that it allows water to be redirected to another location in the model instead of being permanently removed from the model.	
Lake	Simulates interaction between mining lakes (quarries) or reservoirs and the ground water system	Computes lake stages and performs an accounting of inflows/outflows; module was enhanced by District staff
Operations	Simulates the surface water transfer of water based on the availability of water	
Wetland	Simulates the overland flow in wetlands using the uppermost model layer	Enhanced to also simulate either specified or system dependant water diversions within wetlands
General Head Boundary	Simulates ground water exchange between selected cells and a specified boundary as a function of water level difference	Boundary stages are usually based on measured stages or stages computed by the SFWMM

Table F-1. MODFLOW Packages Used in the LEC Subregional Models. (Continued)

Water Supply and Management		
Well	Simulates withdrawals from wells	Includes Public Water Supply (PWS), irrigation, and Aquifer Storage and Recovery (ASR) wells; enhanced by the District to read multiple input files
Pumpage Reduction	Simulates wellfield withdrawal cutbacks as a function of water level in trigger wells and in Lake Okeechobee; simulates LEC water shortage policy associated with saltwater intrusion	Cutback zones are based on SFWMM, refined to include more details; SFWMM simulates the timing of Lake Okeechobee cutbacks
Reinjection Drainflow	Simulates the backpumping of seepage into impoundments by returning seepage collected in perimeter canals back to the impoundments	At the present, this module cannot be applied to impoundments that are relatively small or narrow
Solution Algorithms		
Strongly Implicit Procedure (SIP)	A mathematical solution algorithm internal to the model	Usually used
Preconditioned Conjugate Gradient (PCG)	A mathematical solution algorithm internal to the model; more computationally rigorous than SIP	Used only occasionally when model experiences convergence problems

Relationship to the SFWMM

The regional model covers the entire LEC Planning Area with two mile by two mile grids (square mesh) and simulates the systemwide hydrologic implications of a selected alternative. The SFWMM simulates the ground water system within its boundary using a vertically aggregated, single layer to mimic the composite effects of the nonhomogeneous surficial aquifer. Conversely, the subregional models typically use a stratigraphic, three-dimensional approach in which stratification within the surficial aquifer is simulated using multiple layers with intervening, semiconfining units that can transfer water from one layer to another. Furthermore, the ground water models typically consist of 500 feet by 500 feet spatial cells and up to seven layers. Both the regional model and the subregional models, however, have a stress period (i.e. a time increment for hydrologic stresses) and a time step (i.e. a time increment for numerical computation) equal to one day.

As with any hydrologic model, the use of these high resolution ground water models for a particular scenario requires both spatial and temporal information at their boundaries (i.e. at external boundaries and internal boundaries such as canals) along with information at locations of imposed hydrologic stresses (e.g. a pumping well or a structure discharging into a wetland). This information can include, but is not limited to, water levels, discharges at structures, recharge, potential ET, and withdrawals from Public Water Supply (PWS) wells. The nature of such information along with its derivation from the results of SFWMM simulations (where applicable) are discussed below.

Outer Boundary Conditions

The General Head Boundary package (**Table F-1**) is applied at all of the cells located along the ground water model boundaries. Water levels are therefore needed to simulate fluxes during all stress periods into and out of the model domain across the northern, eastern, southern, and western faces of boundary cells in all layers. Generally, the eastern face (**Figure F-1**) includes all of the coastal boundary cells and the water levels along this boundary are computed from the nearest tidal station with measured data. A correction is made to the computed head to account for the density difference between the salt water and fresh water. In addition, conductance associated with the general head boundary implementation is progressively reduced with depth (using a quadratic formula) to indirectly force the movement of fresh water towards the upper layers at the freshwater-saltwater interface. This is an approximation for the complex three-dimensional nature of flow dynamics that typically occur near the interface.

The water levels from the remaining faces of the model boundary (northern, western, and southern) are estimated from the SFWMM for all stress periods. For example, the water levels in the ground water model boundary cells located in the Water Conservation Areas (WCAs) are estimated from the corresponding water levels computed in the SFWMM simulation. Again, the same water level is assumed for boundary cells in all vertical layers. In some cases, a primary canal simulated by the SFWMM corresponds to the ground water model boundary. Where this occurs, the canal water levels resulting from the SFWMM run are used to define the heads at this boundary.

Initial Conditions

Similar to the concept of defining heads at a spatial boundary over time is the notion of defining heads at a temporal boundary over space. More specifically, water levels must be specified at each model cell at the beginning of a simulation (i.e. the temporal boundary). Water levels at the beginning of a simulation are derived from the output of the corresponding SFWMM simulation for the initial date (January 1, 1988). The first step in this process involves the use of Geographic Information System (GIS) based techniques to assign water levels corresponding to the SFWMM cells to each of ground water model cells in the respective two mile by two mile cells. Next, the resulting high resolution, initial water level surface is smoothed using the FOCALMEAN function of ARC/INFO. Finally, these initial head values are applied to cells in all layers.

Recharge and Evapotranspiration

For planning based applications of the high resolution ground water models, recharge and ET time series are computed using an ET-recharge model (Restrepo and Giddings, 1994). This is an extension of the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) Program (Smajstrla, 1990). The input rainfall for the AFSIRS model corresponds to the rainfall time series input for each of the SFWMM cells. Moreover, the potential ET rates required by this application are computed using the Penman-Monteith formula for a reference crop of dense grass cover 12 inches in height.

Unlike the rainfall data, the meteorological data necessary for this approach are obtained from selected stations in South Florida.

Canals

Since the River, Drain, and, in certain cases, the Reinjection Drainflow packages are used to represent the canals within a given subregional model domain, canals have been classified (somewhat subjectively) as either rivers or drains, depending on their characteristics. Regardless of the canal classification, however, canal stage time series are required for all canal reaches that are to be included in the model. Because the subregional model simulation periods are a subset of the simulation periods for the SFWMM, it is possible to extract canal stages computed by the SFWMM for a particular scenario for subsequent input to a subregional model. In particular, the canal stages were usually derived from SFWMM simulation results by using hydraulic grade line elevations and slopes computed by the SFWMM at specified locations to estimate hydraulic grade line elevations at all canal reaches included in subregional model simulations. Certain canal reaches, however, were either assigned fixed control elevations or stages that reflect other operational protocol not simulated by the SFWMM (e.g. various canals within Lake Worth Drainage District).

Wetlands

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow in extensive wetland systems located within the model boundaries. This package enables the user to define a wetland layer as the top layer of the model grid while enabling the MODFLOW code to apply the physical laws of overland flow within this layer. Interactions between the wetland layer and the uppermost aquifer layer can also be accounted for.

In certain cases (such as in the South Palm Beach ground water flow model), there are interior structures (e.g. S-10s) which divert water from one wetland system to another (say from WCA-1 to WCA-2A). In such instances, a diversion option in the wetland module is used to take water out from a group of cells in one area (say WCA-1) and spread it over the receiving wetland (say WCA-2A). Water can also be diverted into the model domain from external sources. For example, discharges into the model domain across water control structures at the model boundary need to be simulated using this type of diversion option.

Quarries

At certain locations within the LECSAs, the presence of large mining quarries can impact ground water flow. To account for this, interactions between quarries and the ground water flow system are simulated using the Lake package (Nair and Wilsnack, 1998). This package is essentially the same as a previous version of the Lake package (Counsel, 1998) but modified by District staff in order to better account for the high degree of interaction that usually exists between ground water and quarries located in the LECSAs. The Lake package conceptualizes lakes or quarries as sources or sinks with respect to ground water flow and allows stages within them to fluctuate with time. This can enable a MODFLOW model to simulate quarry stages in addition to ground water levels.

Pumpage

The types of ground water withdrawals accounted for in the subregional model simulations include PWS, irrigation, Aquifer Storage and Recovery (ASR), and seepage return. Withdrawals from PWS and irrigation wells in the subregional model simulations were based on current or future permitted allocations. ASR withdrawals and injections were based on local trigger water levels, as well as a daily accounting of available water determined by the SFWMM simulation of the given scenario. Pumpage from seepage return wells was based solely on the design flow rates for the wells and the pumpage was usually returned to the wetland layer at a designated location.

Interactions with GIS

The preceding discussions reveal that in order to apply the MODFLOW code to a specific ground water flow system, the engineer or hydrogeologist is faced with the voluminous task of defining or quantifying all of the required parameters for each active model cell. Such an endeavor requires a systematic and efficient means of managing large amounts of spatial data. In the case of the LEC subregional models, this would naturally suggest that a spatial database containing parameter based thematic maps or coverages is needed for each subregional area of interest. As one would expect, the most suitable means for constructing such a database is GIS.

The GIS software ARC/INFO was used to construct a separate GIS database for each of the subregional model domains. Each database contains numerous thematic coverages that span, at a minimum, the active model domain and contain the data required to construct model input data sets. Examples of such thematic coverages include land use, canals, hydraulic aquifer properties, wellfields, quarries, etc. Conversely, GIS databases were also set up to enable the conversion of certain model output (e.g. ground water levels) to thematic coverages. This greatly facilitated the visualization and review of simulation results.

Period of Record for Subregional Model Simulations

The period of record selected for the required water supply management scenarios was 1988 to 1990. Most of the entire LEC Planning Area experienced drought conditions that were close to 1-in-10 year drought conditions, enabling the scenario simulations to address issues related to a 1-in-10 year drought (required by HB 715). Also, since the drought conditions historically diminished over 1990, the use of the 1988-1990 period of record allowed for an assessment of postdrought recovery.

In addition to a three-year duration, the subregional model simulations were temporally discretized using constant stress period and time step lengths of one day. This relatively short time step interval was used to minimize the types of errors that can result from using too large of a time step (Lal, in press). Also, performance measures related to wetland hydroperiods or reservoir water levels can be assessed more accurately when daily stress periods and time steps are used.

Model Output

Table F-2 summarizes the different types of output that normally result from a subregional model simulation. It should be noted here that although flow based parameters were computed on a daily basis, most of them were summed over each month before they were written out by the model. This was done primarily to speed up model execution while also conserving disk space.

Table F-2. Various Types of Output Resulting from a Subregional Model Simulation.

Output Parameter	Output Time Increment
Wetland water levels	Daily
Specified wetland diversions	Monthly
System-dependant wetland diversions	Daily
Ground water levels	Daily
Ground water flows	Monthly
Quarry stages	Daily
Seepage return flows	Monthly

SUBREGIONAL MODELS

The LEC water supply planning effort used five subregional ground water models. Each model covers a different geographic area within the planning area and is named for the area: North Palm Beach, South Palm Beach, Broward, North Miami-Dade, and South Miami-Dade.

North Palm Beach County Ground Water Flow Model

Introduction

The North Palm Beach County Ground Water Flow Model, is a modified version of the Half Mole Ground Water Flow Model completed in December of 1989 (Shine et al., 1989). The boundary and hydrostratigraphy (transmissivities, permeabilities, and vertical conductance) of the original Half Mile Ground Water Flow Model were not modified significantly. The Half Mile model used six layers. A seventh layer was added in the North Palm Beach County Ground Water Flow Model to facilitate the use of the Wetlands package (Restrepo et al., 1998). The Drain, Evapotranspiration, General Head Boundary, Recharge, River, Well input files were updated and the Canal, Lake, Operations, Redirected Flow, and Wetland input files were added. These changes are discussed in more detail below in the Physical Features section.

Figure F-3 depicts the active model domain in relation to the predominant features of this area. A. The model domain currently uses a square quarter-mile grid resulting in 116 columns and 80 rows.

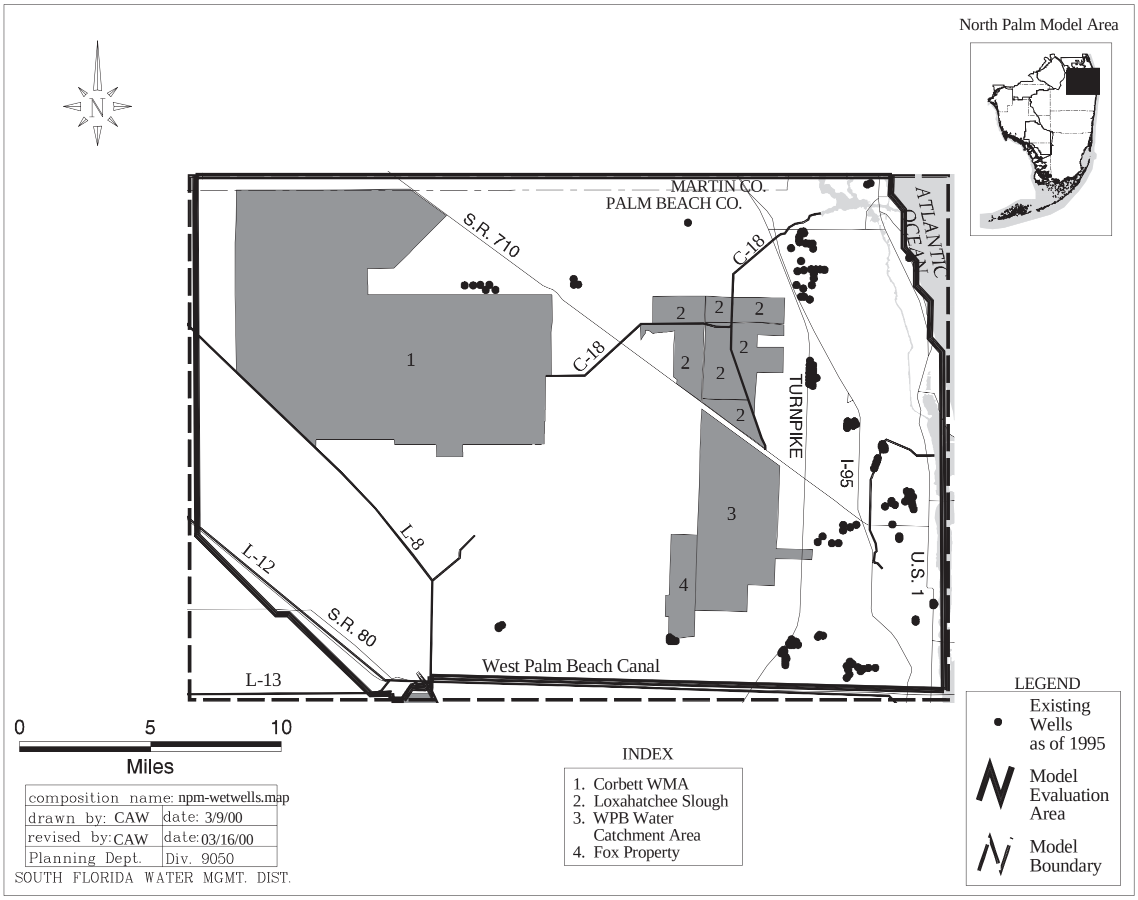

Figure F-3. Model Boundaries and Major Features of the North Palm Beach County Ground Water Flow Model.

Physical Features

Hydrogeology and Model Layers

The North Palm Beach County Ground Water Flow Model was developed to model flow in the SAS. As described in Ground Water Resourse Assessment of Eastern Palm Beach County, Florida (Shine et al., 1989), the SAS within the model boundary is comprised primarily of saturated rock and sediment from the water table down to the relatively impermeable silts and clays of the underlying Intermediate Confining Unit and the upper portion of the Hawthorn Group. The thickness of the SAS varies greatly across the modeling area and ranges from a minimum of approximately 100 feet to over 400 feet. The transmissivity of the SAS also varies greatly spatially, ranging from approximately 10,000 square feet per day in the southwest to over 150,000 square feet per day. Transmissivity within the central portion of the model typically ranges from 20,000 to 60,000 square feet per day with localized maximums on the order of 150,000 square feet per day. This area of higher transmissivity is thought to be an extension of the Biscayne aquifer. This area of higher transmissivity extends from State Road 441 in the west to State Road 809 in the east up to the west leg of the C-18 North Canal. Transmissivity in the remaining portion of the model generally ranges from 10,000 to 20,000 square feet per day.

The model was divided into seven layers of variable thickness. The tops and bottoms of the model layers do not correspond directly to particular aquifer zones within the SAS. In general, the SAS was composed of the following zones based on transmissivity. Layers 1 and 2 are composed of an upper layer of unconsolidated sediments (predominately a fine trace to slightly silty sand) ranging in horizontal permeability from 10 to 100 feet per day and thickness from 20 to 80 feet below sea level (from -20 to -50 ft NGVD). In the Half Mile Ground Water Flow Model (Shine et al., 1989), this upper layer of sand was incorporated as a single layer. To facilitate the use of the Wetlands package in this modeling effort, this layer was divided into two layers. Layers 3 and 4 are zones of higher permeability with yield sufficient to support significant withdrawals. The top of this layer (Layer 3) coincides with the bottom of the unconsolidated sediments. The bottom of this production zone (Layer 4) ranges in depth from 100 to 150 feet below sea level (from –90 to –140 ft NGVD). The Biscayne aquifer, if it is present, typically extends from a depth of 50 to 80 feet below sea level (-30 to -60 ft NGVD). Layers 5 through 7 are zones of moderate permeabilty underlying the production zone ranging in thickness from 20 to 60 feet. The horizontal permeability of this zone typically ranges from 50 to 200 feet per day.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the North Miami-Dade County Ground Water Flow Model are presented in **Figure F-4**.

Surface Water Management System – Canals and Lakes

Surface water systems interactions with the SAS are included in the model through use of the Drain, Lake, River or Wetland packages. The criteria for selecting the approriate package to model surface water management systems (e.g. canals, lakes, and reservoirs) are discussed below.

Surface water bodies that solely drain the SAS were assigned to the Drains Package. These drains were identified and located using quarter-mile grid. The hydraulic conductivity and thickness of the sediment associated with these drains was adjusted during calibration. In some cases the drain conductance approached the hydraulic

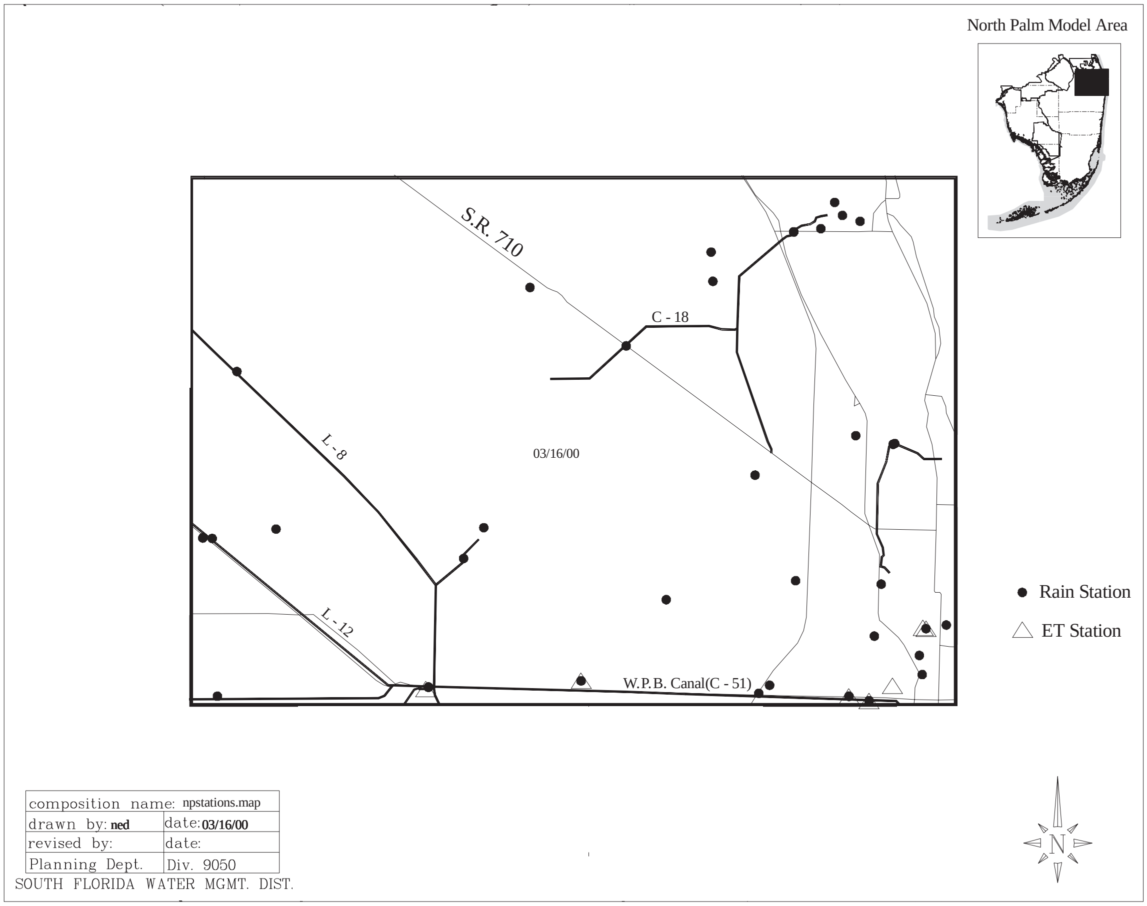

Figure F-4. Rainfall and Evapotranspiration Station Locations used in the North Palm Beach County Ground Water Flow Model.

discharge capacity of the surface water management system indicating that these areas groundwater water levels were predominately controlled by the discharge capacity of the surface water systems.

The Canal Package is currently applied to areas with complex operational rules or discharge limitation. For example, the canal package is used to limit the discharge rate from the developments. Included within the model are all or portions of the following District canals: C-17, C-18, C-18 West, and the West Palm Beach Canal (C-51) (**Figure F-6**). In addition, numerous secondary canals affect ground water levels within the modeling area.

The Lake Package was added to facilitate the modeling of a proposed reservoir located approximately one mile north of the C-51 Canal and less than a 0.25 miles west of the L-8 Canal. The proposed reservoir currently covers approximately two square miles and provides 48,000 acre-feet of storage volume. The Lake Package was added to improve the models numerical stability and better simulate features of the proposed reservoir (e.g. slurry wall, flat surface water, and the potential to compartmentalize the reservoir and operate these compartments at different levels). The proposed storage range of 30 feet (from a maximum control level of 24 ft NGVD to a minimum control level of -14 ft NGVD) is substantial and warrants the use of this package.

Surface water bodies which can both drain and provide recharge to the SAS were assigned to the River Package. The hydraulic conductivity and thickness of the sediment associated with these drains was adjusted during calibration. Surface water bodies with complex operations were handled by separate or combined application of the Wetland, Canal, and Operations packages. The stages estimated by the SFWMM were used to specify the control levels for the C-18, C-18 West, C-17, and C-51 canals.

The recently developed Operations Package was implemented to simulate the surface water transfer of water within the North Palm Beach County ground water flow model. For example, the Operations Package allows the user to set criteria that transfers water from the proposed L-8 Basin Reservoir to the West Palm Beach Water Catchment Area and subsequently to the Loxahatchee River based on the availability of water in the L-8 Reservoir (stage) and the need in the West Palm Beach Water Catchment Area (stage) or discharge to the Northwest Fork of the Loxahatchee River.

Wetlands

The major wetland systems within the active model area are the J.W. Corbett Wildlife Management Area, the Dupuis Reserve, Loxahatchee Slough, the West Palm Beach Water Catchment Area, and the Fox Property. Surface water elevations within these wetlands are influenced by ground water levels, inflows, outflows, rainfall, ET, and topography.

The Wetlands Package (Restrepo et al., 1998) was used to simulate overland flow along with interactions between the surface water and ground water within areas where either overland flow, surface storage, or both are important. For example, the overland flow is very important in the J. W. Corbett Wildlife Management Area, because wet season rainfall typically exceed the ground water drainage rates resulting in surface water accumulation and runoff. The direction and rate of the overland flow resulting from this runoff is determined by the Wetland Package based on the topography, surface water elevation, and Kadlec equation for wetland flow. Both ponded surface water and shallow geology within the wetland layer (Restrepo and Montoya, 1997) was used to minimize the number of model layers, and to avoid the periodic drying of cells.

The Redirected Flow Package is used to remove water from the J. W. Corbett Wildlife Management Area. This package is almost identical to the Drains Package except that it allows water to be redirected to another location in the model instead of being permanently removed from the model.

Water Use

Most of the ground water withdrawals in northern Palm Beach County are for PWS purposes and occur at the wellfield locations shown in **Figure F-4**. Pumpage for golf course irrigation and local domestic supplies also occurs at various locations. During the calibration period and the 1995 base case, approximately 14.2 million gallons per day (mgd) of irrgation demands were supplied from the SAS. Due to land use changes and the availability of reuse water, this daily demand was reduced to 9.0 mgd for 2020 demands. The primary source of PWS in this region is the SAS however, the Village of Jupter does obtain a significant portion of its PWS from Reverse Osmosis of Floridan aquifer water. **Table F-3** provide a list of the yearly withdrawals from the SAS during the calibration period. These values were estimated from monthly raw water demand figures recorded in the SFWMD regulatory database. **Table F-4** lists SAS withdrawals for the 1995 and 2020.

Table F-3. North Palm Beach County Public Water Supply Withdrawals for the Calibration Period

Utility	Permit Number	Withdrawals (MGD)								
		1987	1988	1989	1990	1991	1992	1993	1994	1995
Town of Jupiter	50-00010-W	8.0	8.7	9.4	9.4	8.7	8.6	9.2	9.4	9.5
Mangonia Park	50-00030-W	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.3
Tequesta	50-00046-W	1.3	1.6	1.6	1.0	1.1	1.5	1.2	1.4	1.4
PBC 1W	50-00135-W	0.2	0.3	0.5	0.5	0.7	0.2	0.1	0.1	0.1
PBC 2W	50-00135-W	3.7	4.9	5.0	5.1	4.5	5.6	6.8	6.7	7.4
PBC 8W	50-00135-W	6.6	6.4	8.4	8.5	10.1	9.9	10.6	11.1	11.2
PBC/Century Utility	50-00178-W	0.9	0.9	0.9	0.8	0.8	1.2	0.6	0.4	0.4
Seacoast	50-00365-W	12.6	12.0	15.6	14.3	13.8	13.6	14.8	14.1	14.5
Royal Palm Beach	50-00444-W	1.8	1.8	2.0	1.8	1.8	1.6	1.9	2.0	2.2
Riviera Beach	50-00460-W	8.2	8.3	8.1	7.5	8.4	9.0	9.0	9.0	9.0
United Technologies	50-00501-W	1.0	1.0	1.0	0.7	0.7	0.6	0.6	0.6	0.6
Lion Country	50-00605-W	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
City of West Palm Bch	50-00615-W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Good Samaritan Hospital	50-00653-W	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		45.1	46.9	53.4	50.5	51.4	52.6	55.5	55.4	56.9

Features of the Outer Boundary

As shown in **Figures F-1** and **F-3**, the outer model boundary consists of the following:

- The Atlantic Ocean and Lake Worth Lagoon (east)
- The C-51 Canal (south)
- The L-10 and L-12 Canals (southwest)
- The Dupuis Area (west)
- The Palm Beach County line (north)

Table F-4. North Palm Beach County Public Water Supply Withdrawals.

Utility	Permit Number	Withdrawals (MGD)	
		1995	2020
Town of Jupiter	50-00010-W	9.5	13.2
Mangonia Park	50-00030-W	0.3	0.3
Tequesta	50-00046-W	1.4	1.8
PBC 2W	50-00135-W	6.5	10.0
PBC 8W	50-00135-W	12.1	18.6
PBC 2W & 8W	50-00135-W	18.7	28.6
Seacoast	50-00365-W	14.5	28.4
Royal Palm Beach	50-00444-W	2.2	0.0
Riviera Beach	50-00460-W	9.0	11.7
United Technologies	50-00501-W	0.6	1.1
Lion Country	50-00605-W	0.1	0.1
City of W. Palm Bch	50-00615-W	25.2	42.0
Good Samaritan Hosp.	50-00653-W	0.4	0.4
		100.4	156.2

Each of these boundaries was incorporated into the model using the General Head Boundary Package. Equivalent freshwater heads were used along the coastal/Lake Worth Lagoon boundary. Along the northern and western boundaries, stages were based on water levels estimated by the SFWMM. The eastern boundary data sets were modified to use tidal data from the tailwater readings of the S-155 Structure with adjustment to correct for the affect of discharges from the S-155 Structure. In addition, equivalent freshwater heads were developed and applied for the eastern boundary. No general head boundary cells were used along the southern boundary because the C-51 Canal stages control the ground water levels in this area and because the use of general head boundary cells could introduce an artificial source of water during the alternative analysis.

Model Calibration

The periods of record selected for history matching was 1987-1995, which includes both a relatively dry hydrologic period (1989-1990) and a relatively wet hydrologic period (1993-1995). For this calibration period, the objectives was to adjust the input factors within reasonable ranges to achieve agreement with the observed data 90 percent of the time. Of the 19 calibration sites, 16 met the criteria of being within one foot of the observed value for more than 75 percent of the time. While this agreement between the observed data and input factors is only 84 pecent, no well is below the observed value more than 50 percent of the time. The three wells that did not achieve the desired level of agreement are as follows:

- **SM-009 Donald Ross Road and I-95**. The water levels in this area are greatly influence by the undocumented withdrawal rates of Meca

Farms during the calibration period. Sensitivity anlaysis indicated that varations in the pumping rate could, by itself, explain the discrepancy in water levels.

- **PB-0685 - C-51 West**. The lack of calibration is thought to be a result of a combination of needing to modify (reduce) the transmissivity in this area conbined with the complexity of the Fox Trail Drainage System.
- **PB-0561 - Royal Palm.** In general, this well has good calibration, however its score of 70 percent is below the target value of 75 percent.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. At some gages, data only exist over a fraction of the total period of record and result in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels. In contrast, the model computes water levels at the end of each daily time step.

Recommendations and Conclusions

Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequate for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s). The locations of such performance measures should be within the evaluation area discussed previously. Furthermore, it is suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

Future Improvements

Certain improvements to the model are recommended in order to enhance the model’s ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

- Additional runs should be performed to improve the calibration of the southwestern portion of the model (PB-0685). These additional runs should include exploring how calibration is affected by reducing the transmisssivity in the southwestern portion of the model. Specifically, evaluation of the dewatering rates at the Palm Beach Aggregate Quarry (located imediately west of the L-8 Canal and approximately one mile north of the C-51 Canal) indicate a SAS transmissivity on the order of 2,000 square feet per day. The model currently has a transmissivity of approximately 10,000 square feet per day in this area. A cursory site visit to indentify key features of the Fox Trail Drainage System is also recommend.

- Additional runs should be performed to improve the model's performance as follows: 1) the water levels in the West Palm Beach Water Catchment Area are too high during wet periods and the operational rules need to be modified to lower these levels, 2) the location and operational rules for ASR associated with the West Palm Beach Water Catchment Area should be optimized, 3) the operational rules for the ASR associated with the C-51 Canal need to be changed substancially as they continue to pump during dry period, 4) optimize the criteria and distribution of recharge water for the Village of Jupiter, and 5) optimize the criteria and distribution of recharge water for Seacoast Utilities to protect the wetland preserve in the proposed Golf Digest Project.
- Minor modifications should be made to existing postprocessing programs to facility the rapid review of performance measures and facilitate a more direct comparison of water budgets with the SFWMM results. These changes would faciliate the review of identified performance measures without extensive postprocessing for web posting. These modification would include developing process to allow the comparision of canal base flow and water budgets.

South Palm Beach County Ground Water Flow Model

Introduction

The South Palm Beach County ground water flow model is the third in a series of models developed for the Surficial Aquifer System (SAS) within Palm Beach County. The first models were developed by Shine, et. al. (1989) and used to assess the ground water resources of eastern Palm Beach County. In particular, this effort involved the development and application of two models: one for the northern portion of the county (north of the C-51 Canal) and the other for the southern portion (south of the C-51 Canal). A second version of the model was developed by Yan, et al. (1993) in which the two models for the northern and southern portions of the county were combined into one model. The current version of the model includes significant refinements in both spatial and temporal resolution while incorporating major wetland systems (e.g. WCA-1 and WCA-2A) along with a detailed representation of the Lake Worth Drainage District canal system. The model has been developed specifically to support the Central and Southern Florida Flood Control (C&SF) Project Comprehensive Review Study (Restudy), the subsequent Comprehensive Everglades Restoration Plan (CERP), and the LEC regional water supply planning process.

Model Domain

The model encompasses the portions of Palm Beach County and northern Broward County shown in **Figure F-5**. The northern boundary of the model is located along the M Canal, Clear Lake, and Lake Mangonia. The western boundaries of the active model area include the L-8 Canal, the L-7 Levee and Borrow Canal (WCA-1), the L-6 Levee and Borrow Canal (WCA-2A) and the L-38E Levee and Borrow Canal (WCA-2A). The southern boundary of the model traverses the L-35B Levee and Borrow Canal along with the C-14 Canal in Broward County. The eastern boundary of the model is located along the intercoastal waterway. A subset of the active model domain was defined where the model results of planning based applications could be used for decisionmaking purposes. This evaluation area of the model is shown in **Figure F-5**.

Horizontal and Vertical Discretization

The South Palm Beach model domain was discretized spatially into 430 rows and 324 columns using 500-foot square cells. The model is discretized vertically into five layers of varying thickness, with the wetland layer as the uppermost layer and the bottommost layer terminating at an elevation of –300 ft NGVD.

Physical Features

Hydrogeology

The SAS is an unconfined aquifer system recharged by rain, and by leakage from canals and other surface water bodies. Data from existing well logs were used to determine the aquifer extent and construct a conceptual hydrostratigraphic model. The top wetland layer is restricted to the extensive wetland systems within the model domain and includes WCA-1, WCA-2A, the Strazzulla Tract, and the Loxahatchee Mitigation Bank areas. It consists of ponded surface water, as well as the peat, sand, and caprock layers underlying the wetlands. The bottom elevation of the wetland layer varies from –10 to 5 ft NGVD. Layer two represents the sand and shell layers overlying the Biscayne aquifer, where the bottom elevation varies from –25 to –100 ft NGVD. Layers three and four represent the Biscayne aquifer, the most productive interval within the SAS. The Biscayne aquifer in southern Palm Beach County is also referred as the Zone of Secondary Porosity (Swayze and Miller, 1984) and is characterized by highly solutioned limestones with large hydraulic conductivities. The bottom elevation of the Biscayne aquifer within the model domain varies from –90 to –210 ft NGVD. The relatively large thickness of the Biscayne aquifer and the fact that most of the production wells are present in this zone made it desirable to subdivide this zone into two layers. The model layer below the Biscayne aquifer is comprised of the relatively less permeable sequences of clays, silts, and limestones of the Hawthorn group. It is also considered to be within the intermediate confining unit that lies between the SAS and the Floridan aquifer. The bottom of this layer was set at a constant elevation of –300 ft NGVD since there were not enough data to clearly demarcate the transition from the SAS to the intermediate confining unit.

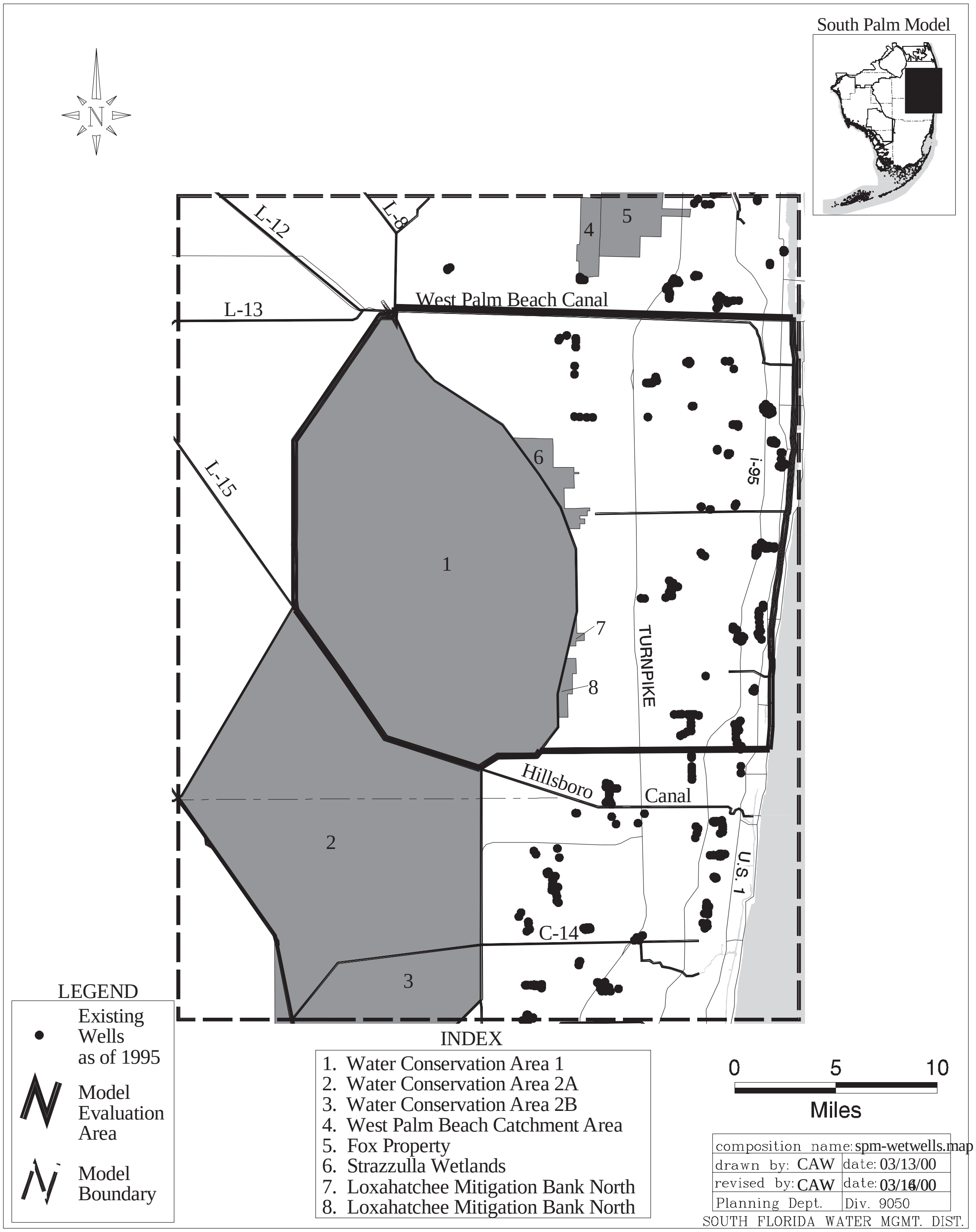

Figure F-5. Model Boundaries and Major Features of the South Palm Beach County Ground Water Flow Model.

The hydraulic properties of the SAS were estimated in part through Aquifer Performance Tests (APTs) performed by the USGS, SFWMD, U.S. Army Corps of Engineers (USACE), and independent consultants. In addition, specific capacity tests, lithologic correlations and geophysical logs were used, where applicable, to estimate the hydraulic properties.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the North Miami-Dade County Ground Water Flow Model are presented in **Figure F-6**.

Surface Water Management

Within the model domain is an extensive network of surface water management systems that have a significant effect on the ground water (**Figure F-5**). The District canals incorporated into the model include the C-51, C-15, C-16, Hillsboro, and the C-14. In addition, the model incorporates the numerous surface water management systems operated by independent drainage and water control districts. These include the Lake Worth Drainage District, the Acme Improvement District, the Loxahatchee Groves Water Control District, the Indian Trail Improvement District, and the West Palm Beach Water Catchment Area south of the M Canal in Palm Beach County. The water control districts within Broward County include the North Springs Improvement District, the Pine Tree Water Control District, the Cocomar Water Control District, Water Control District 2, Sunshine Drainage District, Coral Springs Improvement District, Turtle Run Drainage and Improvement District, Coral Bay Control and Drainage District, and Water Control District 3. Data regarding the operations of the independent drainage districts were compiled from a variety of sources including the system operators, SFWMD permit files, aerial photographs, field inspections, and real estate (REDI) maps.

The interaction of the canal network with the aquifer was modeled using the River and Drain packages. The canals were classified as rivers or drains depending on whether they were maintained or only used to drain the aquifer. For both cases, model input included canal stages and values for a conductance term defining the degree of interaction between the canal and the aquifer. Measured water levels at stage monitoring stations were used to define the hydraulic grade line elevations.

Wetlands

The largest wetlands in the model domain are WCA-1 and WCA-2A. Also included in the model as wetlands are the Strazzulla Tract and the Loxahatchee Mitigation Bank areas that form a buffer between WCA-1 (Loxahatchee National Wildlife Refuge) and the developed areas to the east. WCA-1 has an area of 227 square miles. The vegetation in WCA-1 consists predominantly of wet prairies, sawgrass prairies, and aquatic slough communities along with tree islands which are interspersed throughout the area. WCA-2A has an area of 173 square miles with vegetation cover types consisting of open water sloughs, large expanses of sawgrass intermixed with cattail, and drowned tree

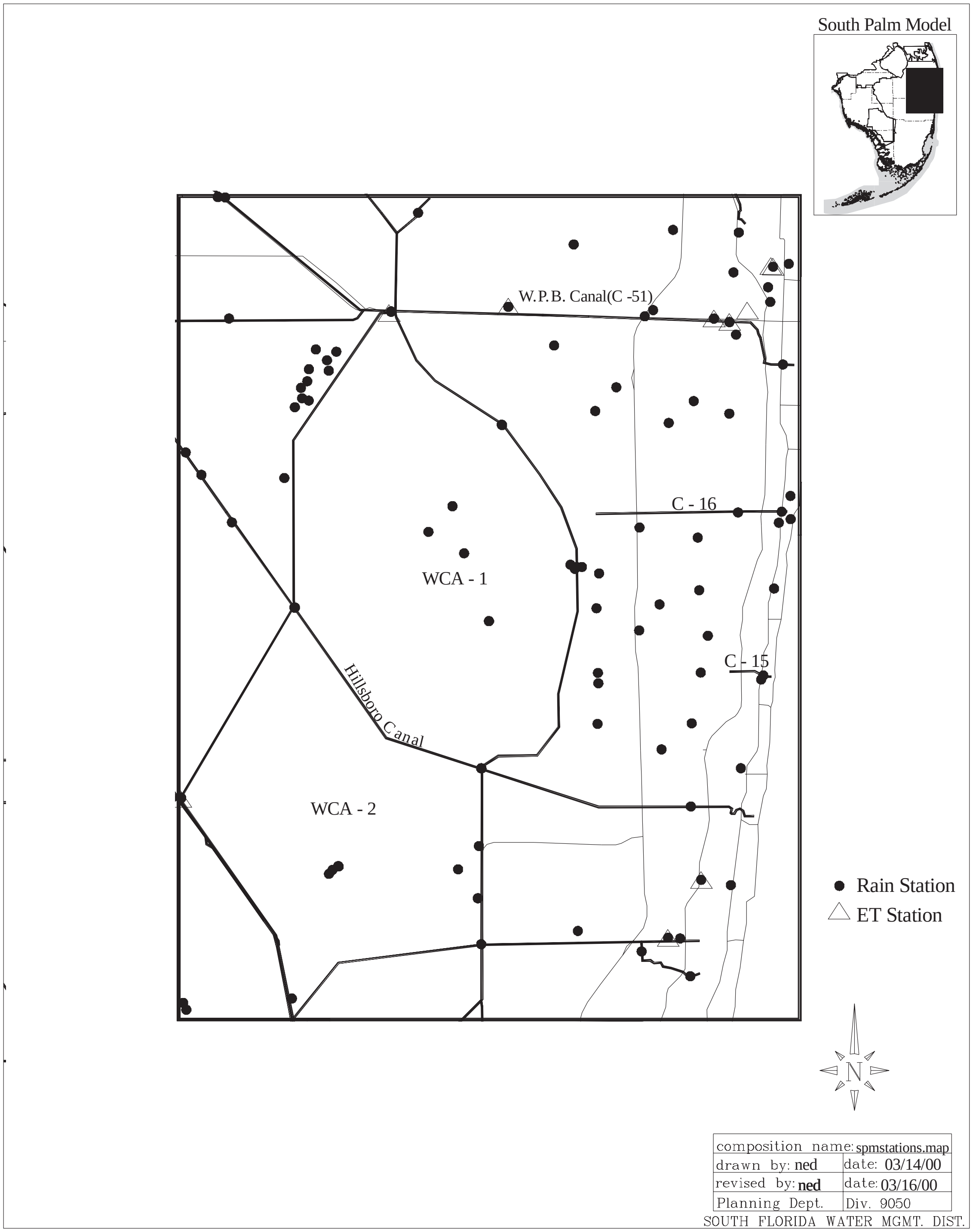

Figure F-6. Rainfall and Evapotranspiration Station Locations used in the South Palm Beach County Ground Water Flow Model.

islands dominated by willow. The Strazzulla Tract contain the only remaining cypress habitat in the eastern Everglades and one of the few remaining sawgrass marshes adjacent to the coastal ridge. The Loxahatchee Mitigation Bank wetlands are located south of the Strazzulla Tract. The spatially varying vegetative cover was accounted for in the Wetland package by the use of vegetative resistance coefficients.

The Wetland package (Restrepo et al., 1998) was the customized MODFLOW package used to simulate overland flow within the wetland areas of the model. The wetland model conceptualizes these areas as isolated wetlands with user specified inflows or outflows. The West Palm Beach Water Catchment Area located south of the M Canal was not modeled as a wetland since it is not only located outside the evaluation area for this model, but it its also adjacent to the model boundary.

Both WCA-1 and WCA-2A were modeled using the diversion option of the Wetland package. For purposes of computational stability the net inflow (difference between the inflows and outflows through the structures of each WCA) was applied uniformly over all the cells of each WCA for each time step. The Strazzulla Tract and Loxahatchee Mitigation Bank areas were modeled as wetlands having no structural inflows or outflows.

Water Use

The locations and attributes of PWS wells were obtained from the District's Water Use and Permits Division. Monthly public water use was extracted from utility reports submitted to the District as a part of the permit limiting conditions. Also included in the reports were the well depths and the casing intervals. Based on this information, along with the percentage allocation among the different wells within each permit, average daily pumpages were assigned to each well in the model data sets. The pumpage was distributed between the model layers based on the layer transmissivities as outlined by McDonald and Harbaugh (1988).

Model Calibration

History matching was performed for two periods of record: a relatively dry period from June 1, 1988, through June 30, 1989, and a relatively wet period from June 1, 1994, through June 30, 1995. Both the history matching periods were preceded by a two-month warm up period in order to help minimize the effects of initial conditions on computed water levels.

The South Palm Beach model was calibrated under both steady state and transient conditions. The transient calibrations completed so far were restricted to history matching of heads and the model was considered to be calibrated at a given well location if the absolute value of the difference between the observed and the computed water levels was less than 1.0 feet for at least 75 percent of that portion of the calibration period of record where data was available. Since most applications of the model involved transient runs, the transient calibration results are reported here.

A total of 37 USGS and SFWMD water level gages were used in the wet calibration period while a total of 24 gages were available for the dry calibration period. The wet period has more observation wells available since some of the District gages in WCA-2 became operational only in late 1994. The locations of all wells and staff gages used for the calibration of the model are given in **Figure F-5**. Although the USGS observation wells have recorders that record the hourly water levels for each day, only the daily maximums are processed and stored in the USGS ADAPS database. Hence, these ground water levels (as opposed to end-of-day water levels) were the only ground water level data available for history matching.

The transient calibration results are shown in **Table F-5** for the wet period of record and in **Table F-6** for the dry period of record. The tables show the percentage of time that the calibration criterion cited above was met. Also shown in the table are the mean error, or bias, and the standard deviation of the residuals.

A comparison of the two calibration periods of record show that, in general, the model performs better during the wet season than in the dry season. This is especially true in the wetland areas. The results also show that while all of the gages in the WCAs met the calibration criteria for the wet period of record, only two of the five gages met the criterion during the dry period of record when the water levels were below open land surface. Apparently, simulations of wetland hydroperiods are fairly accurate when the water levels are above land surface and there is overland flow. It is possible that when no overland flow exists the uncertainties inherent to characterization of the shallow wetland geology result in an under prediction of heads in the wetland layer.

Shortcomings in both the model itself and the water level data prevented calibration targets from being met within certain areas. For example, in the urban areas, it is apparent that the model does not meet the calibration criteria in southeastern Broward County. This is at least partially due to the fact that the operational criteria of the secondary canals within this area cannot be adequately represented by the River and Drain packages. Also, the proximity of observation wells to local stresses sometimes precludes the use of their data for history matching with a finite-difference model. For example, the model was consistently overpredicting water levels at the well PB-1491, which is within the city of Boca Raton’s wellfield. In addition, several of the observation wells had suspected errors in their measuring point elevations. Some of these were corrected or verified while others could not be addressed since the observational wells are no longer in service. Also, limitations in boundary conditions can affect model results at sites located near the boundaries.

Perhaps one of the most significant obstacles to achieving calibration goals was posed by the somewhat inappropriate nature of much of the available water level data. As mentioned earlier, the historical ground water levels currently available from the USGS database are daily maximum values. In contrast, the model computes the heads for the end of each day. Significant differences can exist between daily maximum and end-of-day ground water levels. Also, most of the canal stage data available for the Lake Worth Drainage District, a large portion of the model domain, are only spot measurements and not the mean daily stages that should be used for model input.

Table F-5. South Palm Beach County Calibration Statistics for the Wet Period (June 1, 1994, through June 30, 1995).

Gage Name	Percent Within One Foot	Mean Error (feet)	Standard Deviation Error (feet)	Within Evaluation Area	Comments
PB-809	92.9	-0.329	0.462	N	
PB-99	99.7	-0.085	0.508	N	
PB-1639	53.7	-1.181	0.819	Y	
PB-1491	2.8	2.918	1.009	Y	Boca Raton Wellfield
PB-732	96.5	-0.425	0.324	Y	
PB-1684	94.7	-0.338	0.269	Y	
PB-1661	92.2	-0.343	0.420	Y	
PB-900	79.6	0.571	0.542	Y	
PB-561	73.8	-0.796	0.642	N	
PB-683	79.8	-0.595	0.490	Y	
PB-1680	89.2	0.551	0.365	Y	
PB-685	83.8	-0.034	0.690	N	
PB-445	97.0	-0.148	0.506	Y	
G-1260	43.0	-0.965	1.209	N	Southeast Broward County
G-2739	85.8	0.457	0.567	N	
G-1213	85.9	-0.302	0.783	N	
G-1315	61.5	-0.318	1.049	N	Southeast Broward County
G-1215	27.3	-1.197	2.100	N	Southeast Broward County
G-2031	98.1	-0.092	0.314	N	
G-2147	25.7	-1.717	1.106	N	Southeast Broward County
G-1316	98.9	0.306	0.357	N	
G-853	55.0	-0.756	1.330	N	Southeast Broward County
G-616	94.1	0.019	0.623	N	
1-9[a]	100.0	0.083	0.301	N	
1-8T[a]	100.0	0.098	0.314	N	
1-7[a]	100.0	0.199	0.238	N	
2-17[a]	100.0	0.072	0.189	N	
2-19[a]	76.6	-0.723	0.848	N	Southeast boundary of WCA-2
2A-300_B[a]	100.0	-0.234	0.227	N	
2A-17_B[a]	100.0	0.065	0.194	N	
2-15[a]	100.0	0.118	0.334	N	
WCA2RT[a]	100.0	-0.105	0.169	N	
WCA2F4[a]	100.0	0.064	0.197	N	
WCA2E4[a]	100.0	-0.066	0.219	N	
WCA2E1[a]	95.6	-0.123	0.408	N	
WCA2F1[a]	95.6	-0.206	0.385	N	
WCA2U1[a]	100.0	0.120	0.195	N	

a. USGS and SFWMD Gages in the WCAs

Table F-6. South Palm Beach County Calibration Statistics for the Dry Period (June 1, 1988, through June 30, 1989).

Gage Name	Percent Within One Foot	Mean Error (feet)	Standard Deviation Error (feet)	Within Evaluation Area	Comments
PB-561	69.4	0.062	1.051	N	
PB-809	93.4	-0.453	0.366	N	
PB-99	92.9	-0.620	0.296	N	
PB-683	82.3	-0.500	0.591	Y	
PB-445	97.5	-0.403	0.332	Y	
PB-900	72.7	0.794	0.767	Y	
PB-1491	0.0	7.348	1.502	Y	Boca Raton Wellfield
PB-732	98.0	-0.044	0.433	Y	
PB-88	89.4	0.149	0.675	Y	
PB-1495	15.7	1.322	0.351	Y	May have survey problems
G-1260	76.2	0.374	0.700	N	
G-1213	50.9	0.405	1.061	N	Southeast Broward County
G-1315	46.3	-0.906	1.029	N	Southeast Broward County
G-1215	51.4	0.425	1.126	N	Southeast Broward County
G-2031	95.7	0.444	0.482	N	
G-2147	74.7	-0.508	0.675	N	
G-1316	98.0	-0.362	0.299	N	
G-853	19.8	1.942	0.950	N	Southeast Broward County
G-616	46.0	-1.512	1.061	N	Southeast Broward County
1-9[a]	95.7	-0.616	0.298	N	
1-8C[a]	71.1	0.574	1.035	N	
1-7[a]	65.3	0.364	0.849	N	
2A-300_B[a]	6.1	-1.885	0.462	N	South boundary of WCA-2
2A-17_B[a]	87.1	-0.047	0.698	N	

a. Gage is in the WCAs where water levels were below land surface part of the time.

Conclusions and Recommendations

Model Capabilities and Limitations

The ground water model developed simulates the hydrogeology of the SAS within southern Palm Beach County, as well as the overland flow in the wetland systems. However, the current version of the model has been calibrated only with respect to water levels. The model has not been calibrated for base flows due to resource limitations. This limitation of the model should be kept in mind while evaluating canal base flow or ground water flow across selected boundaries. Consequently, stage duration curves for wetlands and water level hydrographs used for comparative type analysis are the primary type of hydrologic performance measures that the model is capable of supporting.

In addition to the caveats mentioned above, it should be emphasized that the eastern boundary of the model is based on a simplistic representation of the saltwater-freshwater interface within the SAS. The characteristics, position, and movement of this interface are all based on complex factors and principles (e.g., density-driven flow) that cannot be readily incorporated into a ground water flow model that only accounts for freshwater flow. Consequently, the model cannot directly support any performance measures that relate to, or are contingent upon, the shape, position, or movement of the saltwater wedge that, in reality, constitutes the eastern boundary of the ground water flow system.

Future Improvements

The model shall be improved in the future to address the following:

- Sensitivity and uncertainty analysis of all model parameters to improve the overall model calibration
- Acquire the necessary data and resources to calibrate the model for base flows
- Sensitivity analysis of the wetland model parameters to understand the dynamics of the wetland aquifer interactions when the water level goes below the land surface
- Addition of new packages which will incorporate the recharge/ET computations into the simulation model and avoid the use of preprocessed values
- Resolve the discrepancies with the USGS associated with monitored daily maximum values and the model computed end-of-day values
- Formulate cooperative agreements with the secondary water control districts to improve the data collection efforts for stage monitoring
- An improved representation of the saltwater-freshwater interface located along the coastal boundary

Broward County Ground Water Flow Model

Introduction

The District, in cooperation with the Hydrological Modeling Center at Florida Atlantic University, developed a ground water flow model of the SAS to simulate groundwater conditions in central and eastern Broward County, as well as portions of northeastern Miami-Dade County and southeastern Palm Beach County. The model was completed in November, 1999. The new model was constructed and based, in part, on the initial Broward County Groundwater Flow Model developed by Restrepo et al. (1992).

Figure F-7 depicts the active model domain in relation to the predominant features of this area. The model domain was discretized horizontally using a finite-difference grid consisting of 456 rows, 371 columns, and 500-foot square cells. It was calibrated to observed water-levels from the period from January 1988 to December 1995.

Physical Features

Hydrogeology and Model Layers

Only the SAS was included in the Broward County Groundwater Flow Model. The SAS within Broward County essentially consists of (in order of increasing depth) Holocene and recent sediments/soils; the Miami Limestone (formerly referred to as the Miami Oolite); the Fort Thompson formation and/or the Anastasia Formation; the upper unit of the Tamiami formation; the Gray Limestone aquifer; and the lower clastic sediments of the Tamiami formation. Deviations from this general sequence of units, however, can occur in the extreme eastern and western portions of the model domain. For further details, see Perkins (1977), Fish (1991) and Causarus (1985).

The vertical discretization of the Broward model corresponds to the hydrostratigraphy described above. The model has five model layers. The top layer, corresponding to the youngest Pleistocene marine unit deposited in the region (referred to as Q5), generally extends from land surface to an elevation of !5 to -20 ft NGVD. Layer two consists of the next two marine Pleistocene deposits (Q4 and Q3 of Perkins, 1977). Layer three encompass the main production zone of the Biscayne aquifer, and correspond to the middle and late Pliestocene deposits of the Fort Thompson and Anastasia formations. Layer four encompasses the upper unit of the Tamiami formation. Layer five encompasses the Gray Limestone aquifer in the west, and the coastal equivalent of the lower Tamiami aquifer.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the Broward County Ground Water Flow Model are presented in **Figure F-8**.

Canals

The predominant canal network within the Broward County model domain is shown in **Figure F-7**. In addition to all major District canals, it includes numerous lakes and secondary canals in the region. Water levels in all of these canals are controlled and maintained by a network of District and local structures.

Canal-aquifer interactions are included in the model through use of the River and Drain packages. The canals in the region were classified as both rivers and drains depending upon their connections to the regional system. In either case, the required input data included canal stages along with conductance terms depicting the degree of hydraulic interaction between the canals and the aquifer. Canal stages were assigned to the various

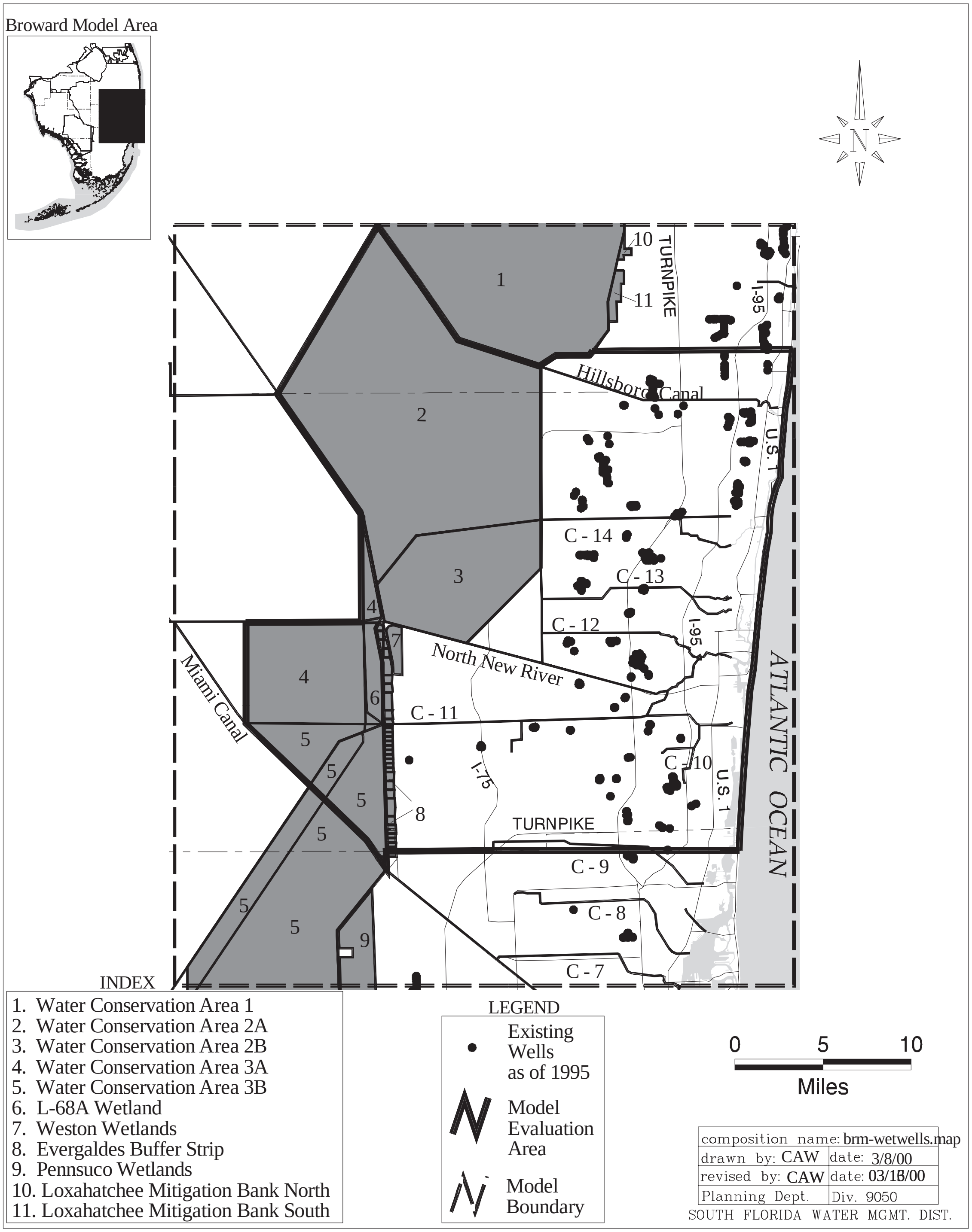

Figure F-7. Model Boundaries and Major Features of the Broward County Ground Water Flow Model.

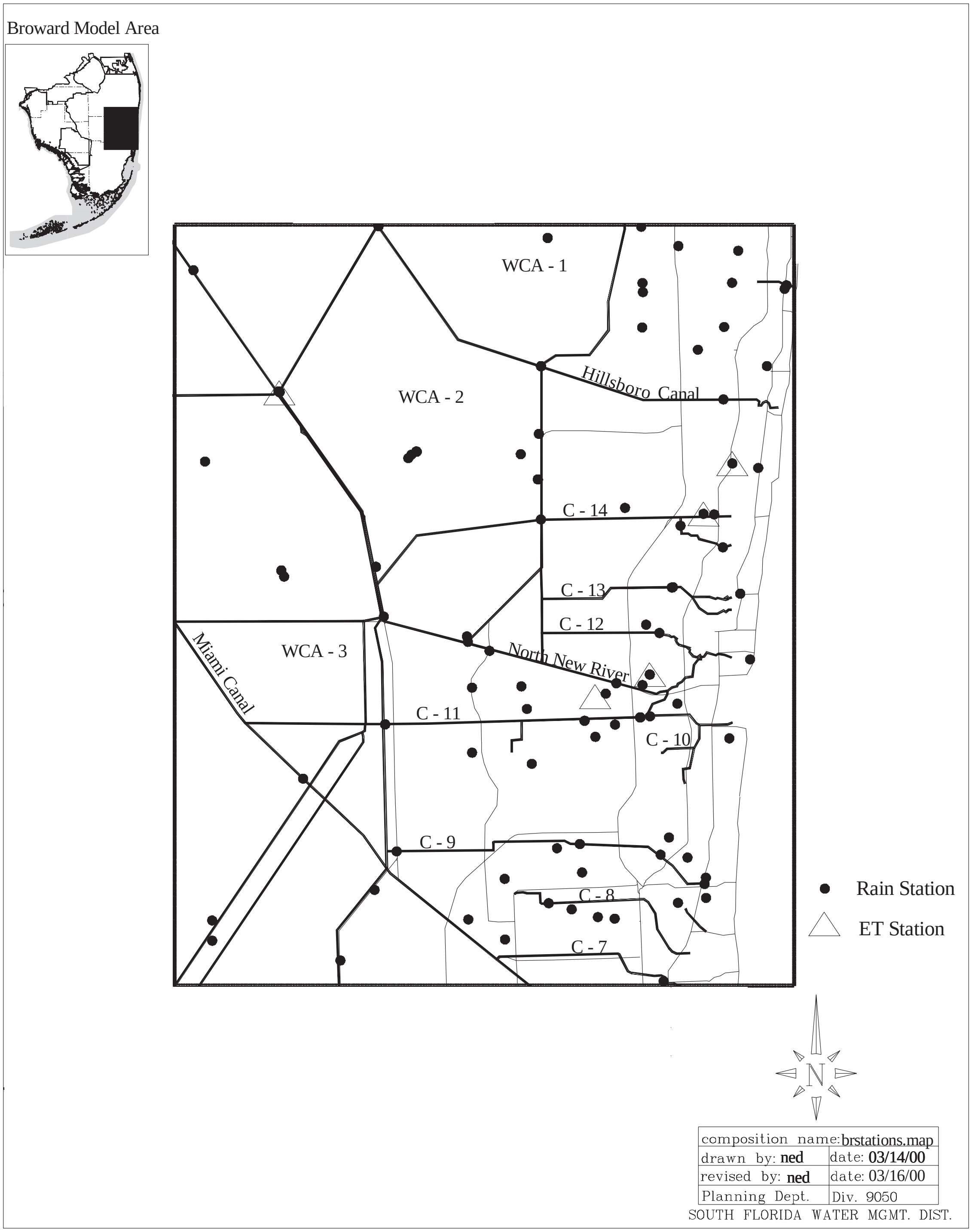

Figure F-8. Rainfall and Evapotranspiration Station Locations used in the Broward County Ground Water Flow Model.

canal reaches by using observed or simulated water levels from the SFWMM, depending upon the secenerio at stage monitoring stations to estimate hydraulic grade line elevations within each reach. A third package utilized in the model was the seepage collection system around the proposed reserviors. This option simulates the removal of water from a canal and subsequent discharge back into the reservior systems.

Wetlands

The major wetland systems within the active model area include all or portions of WCA-1, WCA-2A, WCA-2B, WCA-3A, WCA-3B, the Everglades Buffer Strip and a number small wetland systems located east of the East Coast Protective Levee. Ground water levels, structure discharges, rainfall, ET, and topography influence surface water elevations within these wetlands.

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow within the wetland systems along with interactions between the surface water and ground water. Topographic features influencing the rate of movement through the wetlands (i.e. levees, sloughs, and air boat trails) are explicitly represented in the wetlands package.

Water Use

Ground water withdrawals in Broward County are primarily concentrated in Public Water Supply (PWS), and golf course, landscape, and agricultural irrigation. All permitted withdrawals are explicitly represented in the modeling through the wells package.

Demands for irrigation users were based on the permitted average annual demand. For PWS users, information contained in monthly water use reports submitted to the District was used to assign monthly pumpage rates to each utility. Monthly distributions were based upon the historical record. Actual annual demands were based upon the historical record or projected demand as shown in **Table F-7**, depending upon the simulation. The resulting mean daily pumpage for each utility was then divided among its wells according to a specified percentage for each well.

Features of the Outer Boundary

As shown in **Figure F-1**, the portion of the outer model boundary located east of the levees consists of the following:

- A coastal boundary
- A northern boundary located along the C-15 Canal and southern boundary along the C-6/C-7 canals
- A western boundary within the Everglades

Along the coastal boundary, the required stages and conductance values were determined in the manner explained in the General Subregional Model Features section of

Table F-7. Public Water Supply Demands on the Surficial Aquifer by Utility.

Utility	Permit #	Average Annual Demands (MGY)		Average Daily Demands (MGD)	
		1995 Base	2020 Base	1995 Base	2020 Base
North Palm Beach (NPB)					
Town of Jupiter	50-00010-W	3,463.85	4,818.00	9.49	13.20
Mangonia Park	50-00030-W	122.90	122.90	0.34	0.34
Tequesta	50-00046-W	512.97	638.75	1.41	1.75
Seacoast	50-00365-W	5,276.22	10,369.65	14.45	28.41
Riviera Beach	50-00460-W	3,270.72	4,275.00	8.96	11.71
Good Samaritan Hospital	50-00653-W	127.75	135.05	0.35	0.37
PB Park Commerce	50-01528-W	3.65	357.00	0.01	0.98
Total for NPB Service Area		12,778.06	20,716.35	35.01	56.76
LEC Service Area 1 (LECSA1)					
Deerfield Beach	06-00082-W	4,000.42	4,069.00	10.96	11.15
Parkland	06-00242-W	74.48	112.00	0.20	0.31
North Springs	06-00274-W	515.62	1,715.50	1.41	4.70
Palm Springs	50-00036-W	1,465.87	2,292.20	4.02	6.28
Atlantis	50-00083-W	17.68	0.00	0.05	0.00
PBC (Palm Bch Co) (2W,8W)	50-00135-W	6,821.62	10,442.65	18.69	28.61
Tropical MHP	50-00137-W	33.29	0.00	0.09	0.00
Delray Beach	50-00177-W	4,441.69	5,810.80	12.17	15.92
Century Utilities/PBC	50-00178-W	152.42	0.00	0.42	0.00
Jamaica Bay	50-00179-W	0.00	0.00	0.00	0.00
Lake Worth	50-00234-W	2,611.92	3,556.50	7.16	9.74
Highland Beach	50-00346-W	411.27	508.00	1.13	1.39
Boca Raton	50-00367-W	13,106.54	17,136.75	35.91	46.95
PBC System (3W, 9W)	50-00401-W	5,719.56	16,516.25	15.67	45.25
Royal Palm Beach	50-00444-W	803.70	0.00	2.20	0.00
ACME (Wellington)	50-00464-W	1,475.09	3,504.00	4.04	9.60
Boynton Beach	50-00499-W	3,226.66	6,278.00	8.84	17.20
Manalapan	50-00506-W	365.86	474.50	1.00	1.30
Nat'l MHP (Worth Village)	50-00572-W	70.24	97.00	0.19	0.27
Lantana	50-00575-W	752.29	890.60	2.06	2.44
Lion Country Safari	50-00605-W	18.49	42.00	0.05	0.12
Village of Golf	50-00612-W	152.66	196.00	0.42	0.54
City of West Palm Beach[a]	50-00615-W	9,206.80	15,330.00	25.22	42.00
AG Holley (St of FL)	50-01092-W	24.70	85.00	0.07	0.23
Arrowhead	50-01283-W	0.00	0.00	0.00	0.00
United Technologies	50-00501-W (old) 50-01663-W	212.57	408.80	0.58	1.12
Total for LEC Service Area 1		55,681.44	89,465.55	152.55	245.11
LEC Service Area 2 (LECSA2)					
Seminole Tribe	06-00001-W	126.70	321.15	0.35	0.88
Royal Utility Company	06-00003-W	133.05	149.00	0.37	0.41
North Lauderdale	06-00004-W	1,107.97	2,299.50	3.04	6.30
Hollywood	06-00038-W	7,048.74	8,030.00	19.31	22.00
Miramar	06-00054-W	1,529.04	4,504.10	4.19	12.34
Pompano	06-00070-W	5,929.80	7,300.00	16.25	20.00
Tamarac	06-00071-W	2,044.49	3,650.00	5.60	10.00
Coral Springs I/D	06-00100-W	1,488.85	1,752.00	4.08	4.80

Table F-7. Public Water Supply Demands on the Surficial Aquifer by Utility. (Continued)

Utility	Permit #	Average Annual Demands (MGY)		Average Daily Demands (MGD)	
		1995 Base	2020 Base	1995 Base	2020 Base
Hillsboro Beach	06-00101-W	313.85	360.00	0.86	0.99
Coral Springs City	06-00102-W	2,642.64	3,525.90	7.24	9.66
Plantation	06-00103-W	5,082.17	6,293.00	13.92	17.24
Sunrise	06-00120-W	6,612.50	11,351.50	18.12	31.10
Margate	06-00121-W	3,045.09	4,124.50	8.34	11.30
Ft. Lauderdale	06-00123-W	17,791.10	21,900.00	48.74	60.00
Lauderhill	06-00129-W	2,712.21	2,887.10	7.43	7.91
Davie	06-00134-W	1,112.42	1,929.00	3.05	5.29
Pembroke Pines	06-00135-W	3,405.35	7,300.00	9.33	20.00
Hallandale	06-00138-W	1,261.06	1,277.50	3.45	3.50
Broward 2A (east)	06-00142-W	5,305.05	4,015.00	14.53	11.00
Broward 3A/3C (Picolo)	06-00145-W (old) 06-01474-W	964.80	5,657.50	2.64	15.50
Broward 1A,1B	06-00146-W	3,406.95	4,380.00	9.33	12.00
Broward 3B	06-00147-W (old) 06-01474-W	793.50	0.00	2.17	0.00
Ferncrest	06-00170-W	285.35	401.00	0.78	1.10
Dania Beach	06-00187-W	898.93	730.00	1.85	2.00
Cooper City	06-00365-W	1,278.26	2,226.00	3.50	6.10
South Broward	06-00435-W	241.89	0.00	0.66	0.00
Broward North Regional	06-01634-W	0.00	1,825.00	0.00	5.00
Total for LEC Service Area 2		76,561.76	108,188.75	209.13	296.41
LEC Service Area 3 (LECSA3)					
FKAA[b]	13-00005-W	5,136.91	6,935.00	14.07	19.00
Alexander Orr (WASD)	13-00017-W	61,375.50	103,065.05	168.15	282.37
Florida City	13-00029-W	837.97	1,025.65	2.30	2.81
WASD- Hialeah Preston	13-00037-W	60,875.50	76,723.00	166.78	210.20
REX (WASD-S Dade)	13-00040-W	2,209.80	17,395.90	6.05	47.66
Homestead	13-00046-W	2,354.09	5,694.00	6.45	15.60
North Miami	13-00059-W	2,622.19	3,252.55	7.18	8.91
North Miami Beach	13-00060-W	5,618.61	10,950.00	15.39	30.00
Opa Locka	13-00065-W	0	0	0	0
Homestead AFB	13-00068-W	377.80	0.00	1.04	0.00
Total for LECSA 3		141,408.37	225,041.15	387.41	616.55
LEC Planning Area Total		286,429.63	443,411.80	784.10	1,214.82

a. Demand figures are from surface water.
b. Demand figures are to supply Monroe County.

this appendix. To represent the wedge-like shape of the saltwater interface (Sonenshein and Koszalka, 1996), the location of the boundary cells move inland in the deeper layers of the model. For planning simulations, the coastal boundary, like all of the other outer boundaries, was incorporated into the model using the General Head Boundary package.

Along the northern boundary, stages were based on water levels in canals while the conductance terms were computed in each model layer using the hydraulic conductivity values and dimensions of the boundary cells.

Along the western boundary, heads were fixed using historical and simulated data from District canals corresponding to the boundary. In areas along Alligator Alley, where a canal was not present, average values for northeastern WCA-3A were utilized. The conductance values for these sections of the model boundary were based on the same information used to compute conductance values along the northern and southern boundaries.

Model Calibration

The period of record selected for history matching was 1988-1995. This period of record includes a severe drought (1988-1990), an average condition (1993-1993), and an extreme wet condition (1994-1995). The primary objective for the history matching was to comparing measured and computed water levels at monitoring sites and adjusting model parameters as appropriate to reduce errors to an acceptable level.

Differences between computed and observed water levels are summarized in **Table F-8**. Also provided are mean, minimum, and maximum errors for each site. Due to time constrants and model coverage, calibration of the model in the eastern Boca Raton area was not considered at this time.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. At some gages, data only exist over a fraction of the total period of record and result in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels. In contrast, the model computes water levels at the end of each time step, which, in this case, is the end of each day. Additionally, one can generally not expect a finite-difference based model to replicate ground water levels observed in the immediate vicinity of a pumping well due to limitations imposed by the spatial resolution of the model. Finally, it should be emphasized that the calibration results depicted in **Table F-8** reflect the curent status of the model and are subject to change as improvements to the model are made.

Recommendations and Conclusions

Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequete for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s) to undergo more detailed analyses. The locations of such performance measures should be within the evaluation area discussed previously. Furthermore, it is

Table F-8. Differences Between Computed and Observed Water Levels.

STATION	Minimum Difference	Avgerage Difference	Maximum Difference	Percent
G-1260	0	1.234	3.69	44.95
G-2030	0	0.3916	1.92	94.087
G-2739	0	0.3696	2.4	96.7438
G-1213	0	0.7065	5.24	70.9022
G- 616	0	0.6586	4.3	80.2497
G-1315	0	0.9017	2.91	60.7533
G-1215	0	1.2699	4.9	50.4383
G-2031	0	0.3876	2.07	96.2377
G-2147	0	0.8442	2.95	60.5865
G-1316	0	0.5788	2.57	89.8757
G- 853	0	1.147	3.58	45.5946
G-2443	0	0.3285	2.01	97.479
G-2444	0	1.1182	8.59	53.52
G-2395	0	1.35	4.69	42.9821
G- 820A	0.02	1.4157	3.9	24.2903
G-2033	0	0.4002	3.39	95.292
G-2032	0	0.3639	2.86	95.3366
G-1220	0	0.431	2.64	92.9142
G-2376	0	0.7072	1.87	74.5623
S- 329	0	0.8324	4.15	64.1571
G- 561	0	0.8809	3.49	62.6502
G- 617	0	0.2951	2.3	97.2279
G-2494	0	0.3486	1.5	96.0674
G-2490	0	0.413	1.65	88.5942
G-1221	0	0.2503	4.89	96.7067
G-2488	0	0.6764	1.98	76.584
G-2487	0.01	0.6109	2.04	75
G-2491	0	0.4695	1.73	83.5106
G-2493	0	0.3266	1.19	96.2766
G-2492	0	0.3332	1.22	93.883
G-1224	0	0.7474	3.36	72.1079
G-1322	0	0.3564	1.39	97.0769
G-1223	0	0.4111	3.18	96.3976
G-2495	0	0.5801	1.97	87.381
G-2034	0	0.4525	2.46	91.761
G-2854	0.41	0.9081	1.67	63.8554
G-2615	0.34	0.7954	1.51	63.8554
G-2856	0.39	0.8787	1.44	58.6957
G-2614	0.16	0.7457	1.56	63.8554
G-1226	0	0.4904	7.87	91.2806

Table F-8. Differences Between Computed and Observed Water Levels.

STATION	Minimum Difference	Avgerage Difference	Maximum Difference	Percent
G-2035	0	0.4712	3.88	91.4968
G-1225	0	0.5557	3.15	86.0888
G-1222	0	0.5006	2.4	89.6467
F- 291	0	0.4916	3.87	87.3575
G-1473	0	0.3636	3.52	93.2759
G-1472	0	0.4582	3.06	87.6667
G-1636	0	0.3191	2.18	97.5009
G- 970	0	0.3552	2.58	98.9183
G-1637	0	0.4488	1.79	93.7478
G-3571	0.01	0.5444	3.9	90.6801
S- 18	0	0.2469	2.32	99.2662
G- 852	0	0.2715	2.94	97.6349
G-1166	0	0.2358	2.31	98.3635
CA2B.T	0	1.5231	5.02	33.2188
CA2A300	0.02	1.0553	2.19	47.1976
2A-17_B	0	0.6866	1.89	75.9754
WCA2F1	0	0.8642	1.74	56.4815
WCA2F4	0	0.5317	1.3	92.8241
WCA2E4	0.01	0.4615	1.18	96.5358
WCA2U1	0	0.3433	1.24	96.0739
WCA2RT	0	0.3082	1.15	98.7245
WCA2E1	0.01	0.7699	1.49	63.109
2-15	0	0.5126	1.1	98.2911
2-17	0	0.8124	1.94	66.3317
3-63	0	0.343	1.76	97.2871
3-76	0	0.2799	1.11	99.4859
1-9	0	0.3175	1.17	96.1063
PB-0732	0	0.5067	2.17	87.3835
PB-1661	0	0.3231	3.13	95.8739
PB-1680	0	0.5655	2.88	86.1718
PB-1684	0.26	0.9488	2.79	67.5134
PB-0490	0	0.45	1.88	90
PB-0492	0.03	0.6194	3.7	84.058
PB-0567	0	0.5566	2.41	82.3529
PB-0948	0	0.5185	1.44	89.7436
PB-1006	0.01	0.3967	1.64	93.0233
PB-1063	0	0.5914	1.88	83.908
PB-0897	0.04	0.7574	2.38	69.7674

suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

Future Improvements

Certain improvements to the model are recommended in order to enhance its ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

- Calibration of the model in the east Boca Raton area
- Acquistion of data and ground truthing of canal base flows and canal-aquifer interation of simulated to actual conditions
- Inclusion of a saltwater simulation package to provide a clear understanding of potential movement of the saline interface
- Improved water shortage trigger location and activation levels to provide adequate coverage for the model domain.

North Miami-Dade County Ground Water Flow Model

Introduction

The North Miami-Dade County ground water flow model, also sometimes referred to as version 3.0 of the Lake Belt ground water flow model, is the third in a series of ground water flow models developed for applications in northern Miami-Dade County. The first, version 1.0 of the Lake Belt ground water flow model (Wilsnack, 1995), was developed in support of the *Draft Working Document Lower East Coast Regional Water Supply Plan* (SFWMD, 1993). The second, version 2.0 (Wilsnack et al., 1997; Wilsnack and Nair, 1998), was developed in support of the *Northwest Dade County Freshwater Lake Plan* (SFWMD, 1996). These two older versions of the model are no longer used by the District and are superseded by version 3.0. This current version is the first to include capabilities for simulating certain key surface water processes and was developed in support of both the Restudy and the LEC water supply planning effort.

Figure F-9 depicts the active model domain in relation to the predominant features of this area. The model domain was discretized horizontally using a finite-difference grid consisting of 328 rows, 364 columns, and 500-foot square cells. A subset of the active model domain was defined where the model results of planning based applications could be used for decisionmaking purposes.

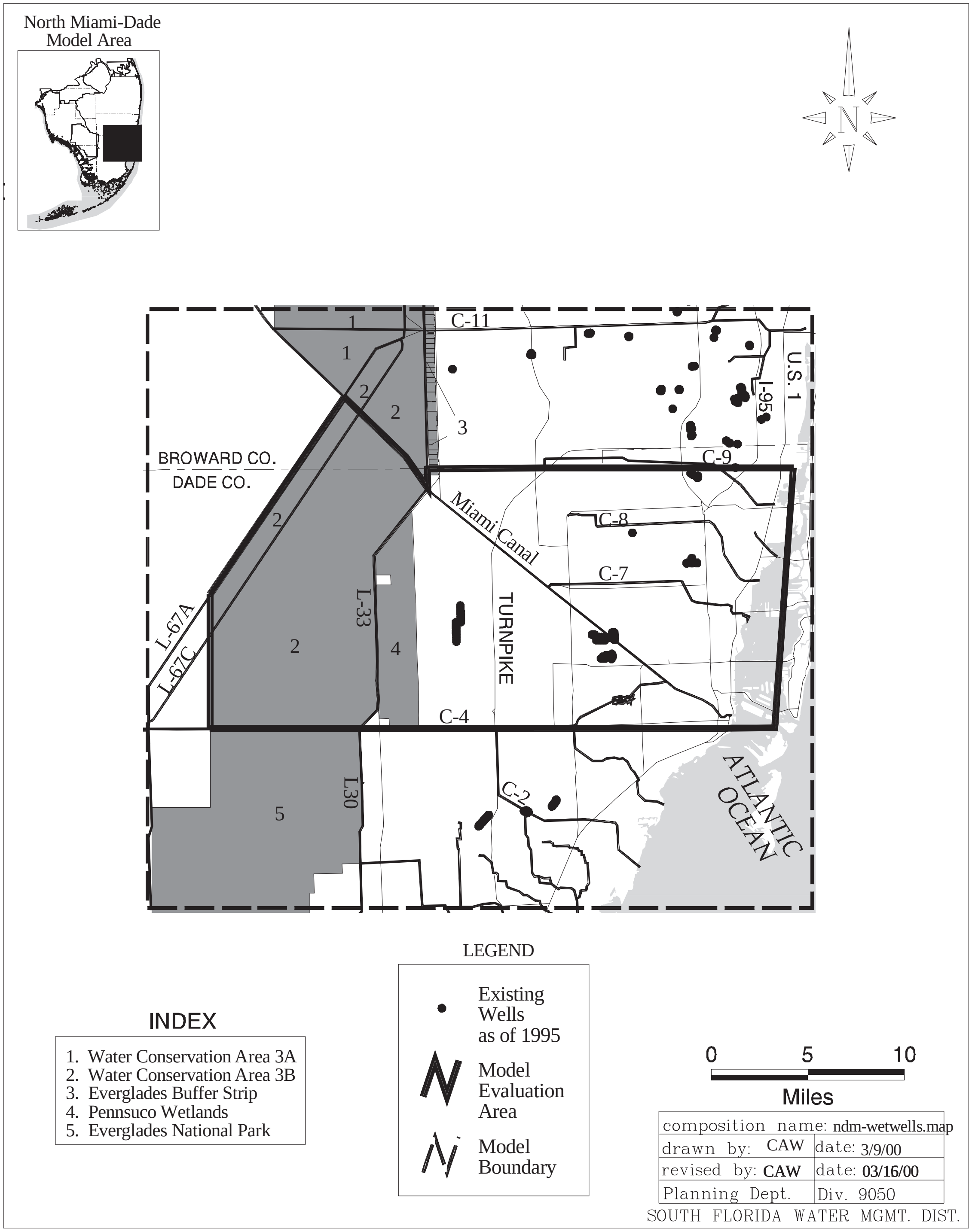

Figure F-9. Model Boundaries and Major Features of the North Miami-Dade County Ground Water Flow Model.

Physical Features

Hydrogeology and Model Layers

Only the SAS was included in the North Miami-Dade County model. The SAS within northern Miami-Dade County essentially consists of (in order of increasing depth) shallow sediments; the Miami Limestone (formerly referred to as the Miami Oolite); the Fort Thompson formation (which includes the Biscayne aquifer); the upper semiconfining unit of the Tamiami formation; the Gray Limestone aquifer; and the lower clastic sediments of the Tamiami formation. Deviations from this general sequence of units, however, can occur in the extreme eastern and western portions of the model domain. For further details, see Fish and Stewart (1991).

The vertical discretization of the SAS consists of eight model layers: a wetland layer (where extensive wetlands exist) extending from the wetland water surface down to an elevation of zero ft NGVD; a top aquifer layer extending from either the bottom of the wetland layer (where extensive wetlands exist) or land surface (elsewhere) to an elevation of –10 ft NGVD; three middle layers with a constant thickness of 20 feet; and three deep layers with a constant thickness of 30 feet. In order to minimize disk space requirements and model execution times, the two bottommost layers were later combined into one layer, resulting in a total of seven model layers used in model calibration and applications.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the North Miami-Dade County Ground Water Flow Model are presented in **Figure F-10**.

Canals

Included within the model are all or portions of the following District canals: C-1W, C-1N, C-2, C-3, C-4, C-5, C-6, C-7, C-8, C-9, C-10, C-11, the C-100 canals, C-123, C-304, L-29, L-30, L-31N, L-33, L-67A, and L-67EXT (**Figure F-9**). In addition, numerous secondary canals owned and operated by Miami-Dade Department of Environmental Resource Management (DERM) are also contained within the model domain. This includes the canal system which protects the Northwest Wellfield. Water levels in all of these canals are controlled and maintained by a network of District and Miami-Dade DERM water control structures.

Canal-aquifer interactions are included in the model through use of the River and Drain packages. Canals were classified as either rivers or drains depending on their physical and operational properties. Most of the canals were classified as rivers. In either case, the required input data included canal stages along with conductance terms depicting the degree of hydraulic interaction between the canals and the aquifer. Canal stages were assigned to the various canal reaches by using measured water levels at stage monitoring stations to estimate hydraulic grade line elevations within each reach.

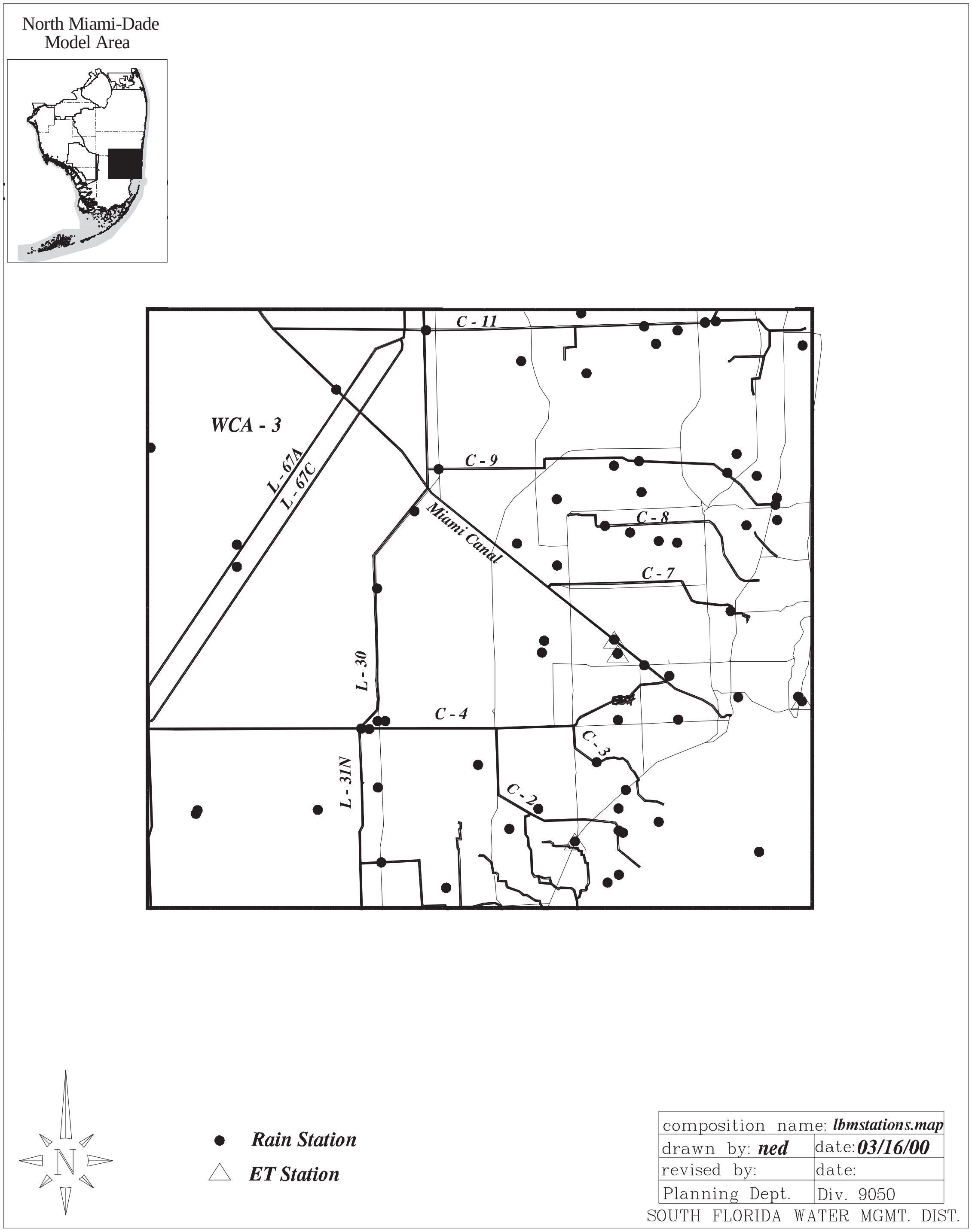

Figure F-10. Rainfall and Evapotranspiration Station Locations used in the North Miami-Dade Ground Water Flow Model.

Wetlands

The major wetland systems within the active model area include WCA-3A, WCA-3B, the northeast corner of Everglades National Park, the Pennsuco Wetlands, and the Bird Drive Wetland (**Figure F-9**). Surface water elevations within these wetlands are influenced by ground water levels, structure discharges, rainfall, ET, and topography.

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow within the wetland systems along with interactions between the surface water and ground water. In this case the option to include both ponded surface water and shallow geology within the wetland layer (Restrepo and Montoya, 1997) was used in order to both minimize the number of model layers, and to avoid the periodic drying of cells. As mentioned previously, this includes all of the sediments and stratigraphic units between land surface and zero ft NGVD. This latter elevation was chosen since it is typically within the range of elevations where the dense limestone layers of the Miami Limestone and upper Fort Thompson formation are situated (Krupa, 1997). These shallow layers, where present, can have a significant influence on interactions between ground water and surface water (Klein and Sherwood, 1961).

Water Use

Most of the ground water withdrawals in northern Miami-Dade County are for PWS purposes and occur at the wellfield locations shown in **Figure F-9**. Pumpage for golf course irrigation and local domestic supplies also occurs at various locations. The primary source of PWS in this region is the Biscayne aquifer, although withdrawals from the gray limestone aquifer also occur at certain wellfields located within the western portions of the model domain (e.g. the Northwest Wellfield).

Daily pumpage from major wellfields within Miami-Dade County was estimated over the 1993-94 period of record. These estimates were based on wellfield operation records maintained by the Miami-Dade Water and Sewer Department (WASD) along with pump capacities. Estimates of daily pumpage based on these data, however, will generally be too high since head losses incurred within the water distribution system are not taken into account. For this reason, the resulting pumpage rates were reduced during the model calibration process.

Daily pumpage was not estimated over the 1988-89 calibration period of record. Instead, information contained in monthly water use reports submitted to the District was used to assign monthly pumpage rates to each water use permit. The resulting mean daily pumpage for each permit was then divided among its wells according to a specified percentage for each well.

Quarries

The region within northern Miami-Dade County commonly known as the Lake Belt can be seen in **Figure F-11**, where the January, 1994, mining configuration is compared with the 1988 mining configuration. Located within this area are numerous limestone mining quarries that typically range from about 30 to 80 feet in depth. These quarries can generally be characterized as having very steep (nearly vertical) side walls that are in direct contact with the aquifer. Input data sets to the Lake package were constructed so as to reflect this conceptualization of the quarries.

Features of the Outer Boundary

As shown in **Figure F-1**, the portion of the outer model boundary located east of the levees consists of:

- A coastal boundary
- A northern boundary located along the C-11 Canal
- A southern boundary that contains portions of the C-1W, C-1N, C-100, and C-100A canals

Each of these boundaries was incorporated into the model using the General Head Boundary package. Along the coastal boundary, the required stages and conductance values were determined in the manner explained earlier in this appendix. Along the northern and southern boundaries, stages were based on water levels in canals while the conductance terms were computed in each model layer using the hydraulic conductivity values and dimensions of the boundary cells.

West of the levee system, the boundary traverses portions of WCA-3A, the L-67A Borrow Canal, the L-67EXT Borrow Canal, and Everglades National Park (**Figure F-9**). The conductance values for these sections of the model boundary were based on the same information used to compute conductance values along the northern and southern boundaries. Boundary stages applied west of the levee system were the closest available measured stages.

Model Calibration

The periods of record selected for history matching were 1988-89 (relatively dry hydrologic conditions) and 1993-94 (relatively wet hydrologic conditions). For each of these periods of record, the objectives for the history matching consist of the following:

- Comparing measured and computed water levels at monitoring sites and adjusting model parameters as appropriate to reduce errors to an acceptable level (Phase I)
- Comparing measured and computed base flows of selected canal reaches and adjusting model parameters as appropriate to reduce errors to an acceptable level while maintaining water level errors within an acceptable level (Phase II)

Given the time frame for completing the model applications needed to support the *LEC Regional Water Supply Plan*, only the Phase I calibration goals were attempted. Phase II of the calibration will be completed at a later date.

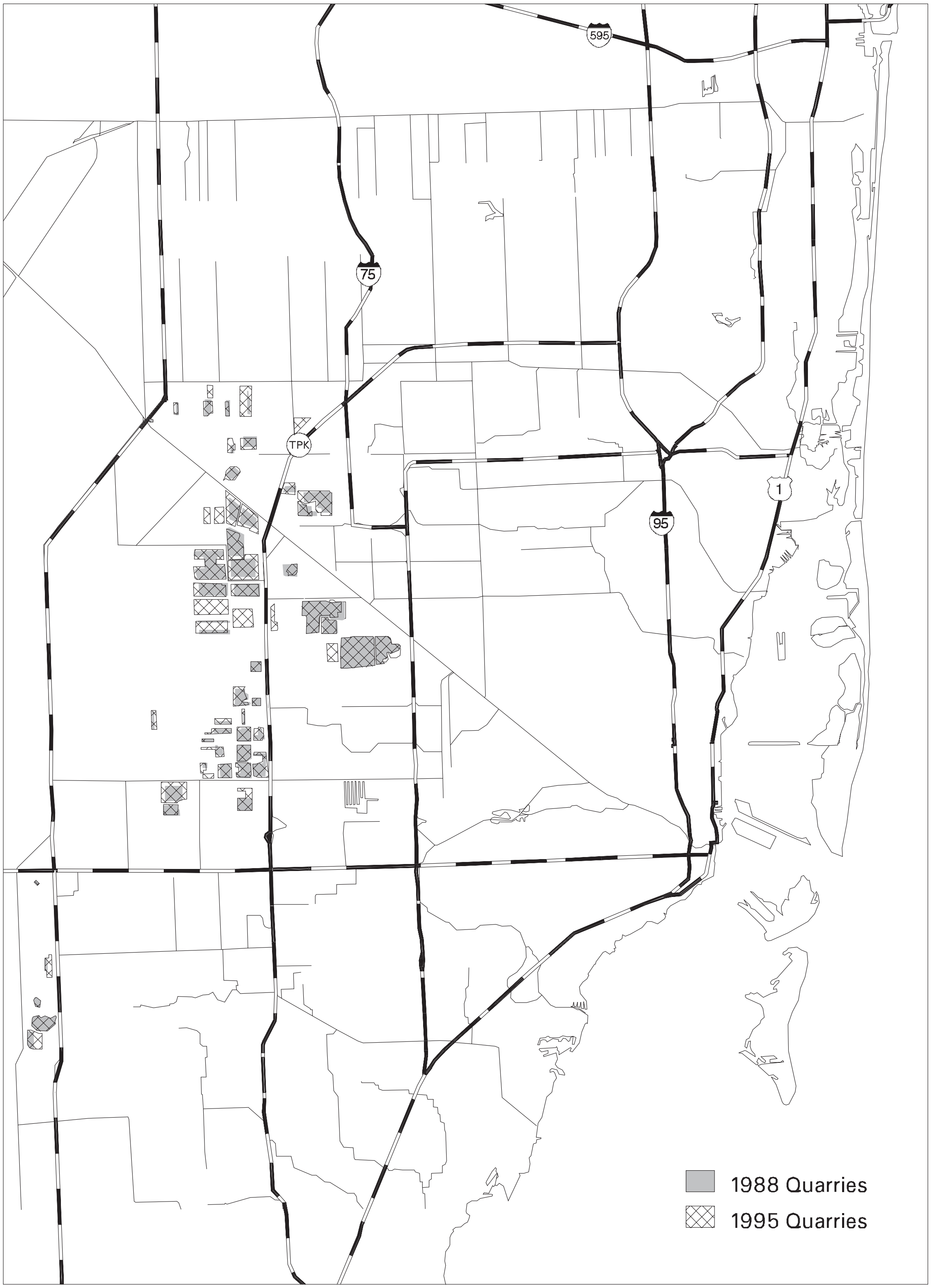

Figure F-11. Quarries Located Within the Lake Belt in 1988 and 1994.

Differences between computed and observed water levels are summarized in **Table F-9** for the wet period of record while **Table F-10** contains the water level residuals for the dry period of record. Also provided are mean error, or bias, and residual standard deviation for each site. In order to minimize any effects of initial conditions on these results, the residuals for the first two months of each period of record were not used in the analysis.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. At some gages, data only exist over a fraction of the total period of record and result in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels. In contrast, the model computes water levels at the end of each time step (i.e. day). Additionally, one can generally not expect a finite-difference based model to replicate ground water levels observed in the immediate vicinity of a pumping well due to limitations imposed by the spatial resolution of the model. Similarily, limitations in boundary conditions can affect model results at sites located near the boundaries. Finally, it should be emphasized that the calibration results depicted in **Tables F-9** and **F-10** only reflect the current status of the model and are subject to change as improvements to the model are made.

Table F-9. North Miami-Dade County Calibration Statistics for the Wet Period of Record (1993-94).

Gage Name	Percent of Days: Within Minimum Criterion (+/- 1.0 ft)	Percent of Days: Within Desired Criterion (+/- 0.5 ft)	Mean Error (Bias) (feet)	Standard Deviation (feet)	Notes
3B-SE_B	100.00	71.46	-0.29	0.37	Surface water station
F-179	98.77	95.28	0.05	0.29	
F-239	92.64	27.71	0.61	0.36	Elevation of measuring point may be questionable
F-291	98.08	81.06	0.22	0.36	
F-319	99.78	96.53	-0.16	0.18	
F-45	98.36	81.52	0.16	0.37	
G-1074B	0.00	0.00	5.23	0.93	Within the Alexander Orr Wellfield Complex
G-1166	98.96	95.41	-0.00	0.22	
G-1223	95.89	64.48	-0.49	0.30	Located near the northern boundary
G-1224	94.39	29.11	-0.63	0.24	Located near the northeast boundary and a wellfield
G-1225	95.77	71.13	-0.32	0.37	See Note 1
G-1226	97.20	31.83	-0.59	0.26	Located near the northeast boundary and a wellfield

Note 1. A possible error occurred in the measuring point datum, or maximum daily measured water levels (published) may not be representative of end-of-day water levels (computed by the model and measured values not published).

Note 2. A discrepancy exists between the SFWMD and USGS surveyed elevation of the measuring point.

Note 3. A possible overestimation of pumping rates was made at nearby pumping well(s).

Table F-9. North Miami-Dade County Calibration Statistics for the Wet Period of Record (1993-94). (Continued)

Gage Name	Percent of Days: Within Minimum Criterion (+/- 1.0 ft)	Percent of Days: Within Desired Criterion (+/- 0.5 ft)	Mean Error (Bias) (feet)	Standard Deviation (feet)	Notes
G-1359	99.33	63.33	-0.28	0.37	Period of Record (POR) starts 8/1/94; located near a mining lake
G-1368A	16.20	14.07	3.26	1.60	Located within Preston-Hialeah/Miami Springs Wellfield
G-1473	98.15	81.31	0.14	0.39	
G-1487	99.58	62.92	-0.46	0.20	Located near the southern boundary; See Note 1
G-1488	100.00	89.83	0.15	0.23	
G-1636	96.57	69.38	-0.32	0.35	See Note 1
G-1637	100.00	78.19	0.31	0.21	
G-2034	93.50	82.06	-0.16	0.43	
G-2035	70.12	5.30	-0.93	0.33	Located near the northeast boundary and a wellfield
G-2495	57.69	11.54	-0.94	0.37	Located near the northern boundary
G-3	10.27	1.44	1.48	0.43	Located within Preston-Hialeah-Miami Springs Wellfield
G-3073	92.45	71.91	0.33	0.41	Influenced by pumping
G-3074	48.46	31.42	1.31	1.18	Located near the PWS well within the Snapper Creek Complex
G-3253	76.34	39.43	-0.06	0.80	Located within Northwest Wellfield Complex; See Notes 2 and 3
G-3259A	80.90	46.61	-0.53	0.45	Located near the Northwest Wellfield Complex; See Notes 2 and 3
G-3264A	100.00	87.27	0.25	0.22	
G-3327	99.18	97.33	-0.05	0.23	
G-3328	100.00	97.85	-0.00	0.20	
G-3329	98.45	91.61	-0.14	0.43	
G-3439	99.72	95.25	-0.11	0.21	
G-3465	99.37	47.47	0.44	0.33	Located near the Preston-Hialeah/Miami Springs Wellfield
G-3466	67.85	27.25	0.74	0.46	Located within Preston-Hialeah/Miami Springs Wellfield
G-3467	99.18	96.10	0.11	0.23	
G-3473	99.13	92.16	-0.12	0.24	
G-3551	100.00	100.00	0.03	0.15	
G-3552	98.91	92.36	-0.00	0.30	
G-3553	99.36	95.85	0.04	0.25	
G-3554	98.75	94.38	-0.02	0.31	
G-3555	99.28	89.53	0.16	0.28	
G-3556	100.00	99.33	0.03	0.21	
G-3557	100.00	98.48	-0.05	0.24	
G-3558	100.00	92.66	-0.10	0.23	

Note 1. A possible error occurred in the measuring point datum, or maximum daily measured water levels (published) may not be representative of end-of-day water levels (computed by the model and measured values not published).

Note 2. A discrepancy exists between the SFWMD and USGS surveyed elevation of the measuring point.

Note 3. A possible overestimation of pumping rates was made at nearby pumping well(s).

Table F-9. North Miami-Dade County Calibration Statistics for the Wet Period of Record (1993-94). (Continued)

Gage Name	Percent of Days: Within Minimum Criterion (+/- 1.0 ft)	Percent of Days: Within Desired Criterion (+/- 0.5 ft)	Mean Error (Bias) (feet)	Standard Deviation (feet)	Notes
G-3559	100.00	98.79	-0.07	0.17	
G-3560	99.27	92.36	0.15	0.26	See Notes 2
G-3561	92.45	53.77	-0.08	0.63	Located near the southern boundary; POR begins 2/94
G-3562	31.97	29.51	-1.26	0.89	POR begins 9/1/94; See Note 1
G-3563	96.69	74.38	-0.39	0.29	
G-3564	90.16	41.80	0.45	0.57	POR begins 9/1/94; See Note 1
G-3565	93.39	16.53	-0.66	0.23	POR begins 9/1/94; See Note 1
G-3566	94.26	85.25	-0.18	0.47	
G-3567	100.00	71.31	-0.23	0.43	POR begins 9/1/94; See Note 2
G-3568	99.11	91.07	0.24	0.30	
G-3570	60.33	10.74	-1.05	0.60	POR begins 9/1/94; See Note 1
G-3571	91.18	75.00	-0.05	0.78	
G-3572	97.52	70.25	-0.35	0.31	POR begins 9/1/94; See Note 1
G-551	86.45	23.00	-0.46	0.59	Located within the Southwest Wellfield Complex; See Note 3
G-553	99.15	75.21	-0.46	0.14	
G-580	98.53	94.55	-0.11	0.33	
G-618	100.00	89.62	0.33	0.14	
G-852	97.69	92.61	-0.07	0.33	
G-855	97.26	88.81	0.23	0.28	
G-968	100.00	90.61	-0.10	0.25	See Note 2
G-970	99.76	92.40	-0.25	0.18	
G-972	97.73	64.77	0.07	0.50	
G-973	100.00	90.70	0.28	0.21	
G-975	100.00	87.60	0.12	0.30	
G-976	100.00	78.98	-0.32	0.22	
NESRS1	100.00	57.70	0.45	0.21	Surface water station; located near southwest boundary
NESRS2	99.79	19.71	0.63	0.21	Surface water station
NESRS3_B	100.00	100.00	-0.22	0.15	Surface water station
S-18	97.55	92.87	-0.14	0.31	
S-19	99.59	48.76	0.44	0.32	Located within Preston-Hialeah/Miami Springs Wellfield
S-68	33.04	9.13	1.18	0.46	Located within Preston-Hialeah/Miami Springs Wellfield
SHARK.1_H	100.00	58.59	0.38	0.25	Surface water station
SITE_34	100.00	92.81	-0.04	0.26	Surface water station
SITE_71	100.00	30.39	0.64	0.22	Surface water station
SITE_76	100.00	56.46	0.46	0.19	Surface water station

Note 1. A possible error occurred in the measuring point datum, or maximum daily measured water levels (published) may not be representative of end-of-day water levels (computed by the model and measured values not published).

Note 2. A discrepancy exists between the SFWMD and USGS surveyed elevation of the measuring point.

Note 3. A possible overestimation of pumping rates was made at nearby pumping well(s).

Table F-10. North Miami-Dade County Calibration Statistics for the Dry Period of Record (1988-89).

Gage Name	Percent of Days: Within Minimum Criterion (+/- 1.0 ft)	Percent of Days: Within Desired Criterion (+/- 0.5 ft)	Mean Error (Bias)	Standard Deviation	Notes
3B-SE_B	100.00	87.16	-0.28	0.19	Surface water station
F-179	99.79	87.27	0.07	0.28	
F-239	85.01	4.52	0.82	0.19	Elevation of measuring point may be questionable
F-291	97.54	78.85	0.31	0.30	
F-319	99.18	95.69	-0.10	0.19	
F-45	100.00	93.84	0.17	0.17	
G-1074B	15.20	7.8	2.77	2.25	Within the Alexander Orr Wellfield Complex; See Note 4
G-1166	100.00	100.00	0.13	0.10	
G-1222	94.58	78.92	0.04	0.52	
G-1223	99.59	74.33	-0.44	0.15	Located near the northern boundary
G-1224	97.13	86.24	-0.30	0.29	Located near the northeast boundary and a wellfield
G-1225	100.00	94.87	0.24	0.20	
G-1226	97.13	60.99	-0.48	0.48	Located near the northeast boundary and a wellfield
G-1368A	69.40	54.62	0.70	0.86	Within Preston-Hialeah/Miami Springs Wellfield; See Note 4
G-1472	97.74	86.24	0.24	0.31	
G-1473	98.36	90.76	0.20	0.28	
G-1487	93.43	71.46	-0.36	0.37	Located near the southern boundary
G-1488	100.00	69.61	-0.35	0.25	See Note 1
G-1636	95.48	77.00	-0.20	0.42	
G-1637	99.79	97.54	0.18	0.19	
G-2034	94.05	74.95	0.04	0.50	Located near the northern boundary; See Note 4
G-2035	91.77	18.11	-0.73	0.25	Located near the northeast boundary and a wellfield
G-3	100.00	97.54	0.18	0.19	Located within Preston-Hialeah/Miami Springs Wellfield
G-3074	42.30	36.14	0.95	0.84	Located near the PWS well within Snapper Creek Complex
G-3253	21.97	9.45	1.61	1.02	Located within Northwest Wellfield Complex; See Note 4
G-3259A	91.17	37.78	0.44	0.47	Located near the Northwest Wellfield Complex; See Notes 2 and 4
G-3264A	98.97	94.66	-0.16	0.23	

Note 1. A possible error occurred in the measuring point datum, or maximum daily measured water levels (published) may not be representative of end-of-day water levels (computed by the model and measured values not published).

Note 2. A discrepancy exists between the SFWMD and USGS surveyed elevation of the measuring point.

Note 3. A possible overestimation of pumping rates was made at nearby pumping well(s).

Note 4. The use of monthly pumpage rates may also be contributing to errors.

Table F-10. North Miami-Dade County Calibration Statistics for the Dry Period of Record (1988-89). (Continued)

Gage Name	Percent of Days		Mean Error (Bias)	Standard Deviation	Notes
	Within Minimum Criterion (+/- 1.0 ft)	Within Desired Criterion (+/- 0.5 ft)			
G-3327	100.00	86.65	0.37	0.15	
G-3328	100.00	97.95	0.29	0.10	
G-3329	99.79	96.71	-0.10	0.13	
G-3439	100.00	77.82	0.18	0.30	
G-3465	100.00	95.28	0.16	0.17	Located near the Preston-Hialeah/Miami Springs Wellfield
G-3466	99.79	87.27	0.34	0.20	Located within Preston-Hialeah/Miami Springs Wellfield
G-3467	100.00	88.09	0.36	0.15	
G-551	66.59	7.86	-0.86	0.30	Located within the Southwest Wellfield Complex; See Notes 1 and 3
G-553	98.77	93.02	-0.31	0.15	
G-580	99.38	94.87	0.03	0.23	
G-596	97.33	77.82	0.04	0.45	
G-618	100.00	100.00	0.24	0.07	
G-852	97.13	93.63	-0.002	0.38	
G-855	100.00	94.87	0.24	0.20	
G-858	97.54	63.24	-0.48	0.23	Located near the southern boundary; See Note 1
G-968	100.00	84.82	-0.22	0.27	See Note 2
G-970	99.18	91.38	-0.27	0.18	
G-972	84.36	16.67	-0.72	0.27	
G-973	100.00	98.36	0.10	0.14	
G-974	99.38	62.83	0.12	0.50	
G-975	74.95	33.88	-0.74	0.38	See Note 1
G-976	71.05	35.11	-0.74	0.46	See Note 1
NESRS1	94.46	89.12	0.04	0.40	Surface water station; located near the southwest boundary
NESRS2	94.05	72.90	0.10	0.45	Surface water station
NESRS3_B	100.00	66.60	-0.28	0.39	Surface water station
S-18	100.00	100.00	0.09	0.10	
S-19	100.00	95.07	0.14	0.18	
S-68	99.18	87.47	0.27	0.25	
SHARK.1_H	100.00	94.25	0.16	0.21	Surface water station

Note 1. A possible error occurred in the measuring point datum, or maximum daily measured water levels (published) may not be representative of end-of-day water levels (computed by the model and measured values not published).

Note 2. A discrepancy exists between the SFWMD and USGS surveyed elevation of the measuring point.

Note 3. A possible overestimation of pumping rates was made at nearby pumping well(s).

Note 4. The use of monthly pumpage rates may also be contributing to errors.

Recommendations and Conclusions

Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequate for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s) to undergo more detailed analyses. The locations of such performance measures should be within the evaluation area discussed previously. Furthermore, it is suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

In addition to the caveats mentioned above, it should be emphasized that the eastern boundary of the model is based on a simplistic representation of the saltwater-freshwater interface within the SAS. The characteristics, position, and movement of this interface are all based on complex factors and principles (e.g., density-driven flow) that cannot be readily incorporated into a ground water flow model that only accounts for freshwater flow. Consequently, the model cannot directly support any performance measures that relate to, or are contingent upon, the shape, position, or movement of the saltwater wedge that, in reality, constitutes the eastern boundary of the ground water flow system.

Future Improvements

Certain improvements to the model are recommended in order to enhance its ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

- The resolution of any outstanding data quality issues related to measured water levels (e.g. correcting errors in measuring point elevations)
- A Phase II calibration that addresses canal base flow and water budgets
- A sensitivity analysis of calibrated model results
- The incorporation of additional surface water modules that would allow canal stages and rainfall recharge to be simulated by the model
- An improved representation of the saltwater-freshwater interface located along the coastal boundary

South Miami-Dade County Ground Water Flow Model

Introduction

In 1999, the District contracted with the Hydrological Modeling Center of Florida Atlantic University (FAU) for construction of a ground water flow model of the SAS to encompass the area of Miami-Dade County south of the C-4 Canal. Contractual work on the model was completed in January 2000.

Figure F-12 depicts the active model domain in relation to the predominant features of this area. The model domain was discretized horizontally using a finite-difference grid consisting of 430 rows, 367 columns, and 500-foot square cells. It was calibrated to observed water-levels from the period from January 1988 to December 1990.

Physical Features

Hydrogeology and Model Layers

Only the SAS was included in the South Miami-Dade County Ground Water Model. The SAS within southern Miami-Dade County essentially consists of (in order of increasing depth): shallow sediments; the Miami Limestone (formerly referred to as the Miami Oolite); the Fort Thompson formation; the upper unit of the Tamiami formation; the Gray Limestone aquifer; and the lower clastic sediments of the Tamiami formation. Deviations from this general sequence of units, however, can occur in the extreme eastern and western portions of the model domain. For further details, see Fish and Stewart (1991) and Causaras (1987).

The vertical discretization of the South Miami-Dade model corresponds to the hydrostratigraphy described above. The model has four model layers. The top layer, corresponding to the Miami Limestone unit, extends from land surface to an elevation of -1 to -17 ft NGVD. Layers two and three encompass the Biscayne aquifer, and correspond to the Fort Thompson formation and upper unit if the Tamiami formation. Layer four encompasses the Gray Limestone aquifer in the west, and the coastal equivalent of the lower Tamiami aquifer.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the North Miami-Dade County Ground Water Flow Model are presented in **Figure F-13**.

Canals

The predominant canal network within the South Miami-Dade County model domain is shown in **Figure F-12**. In addition to all major District canals, it includes numerous lakes and secondary canals, including the vast network of cooling canals

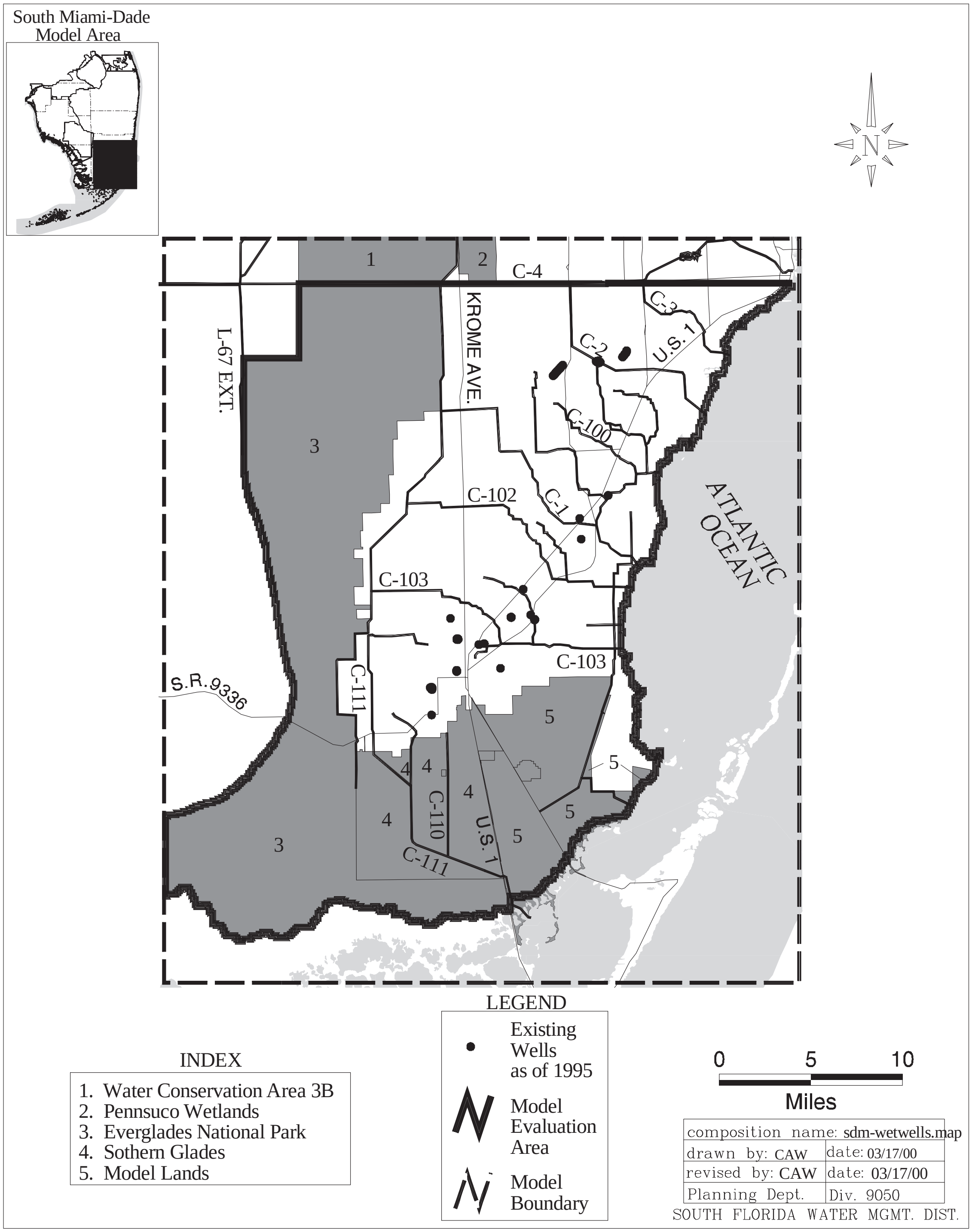

Figure F-12. Model Boundaries and Major Features of the South Miami-Dade County Ground Water Flow Model.

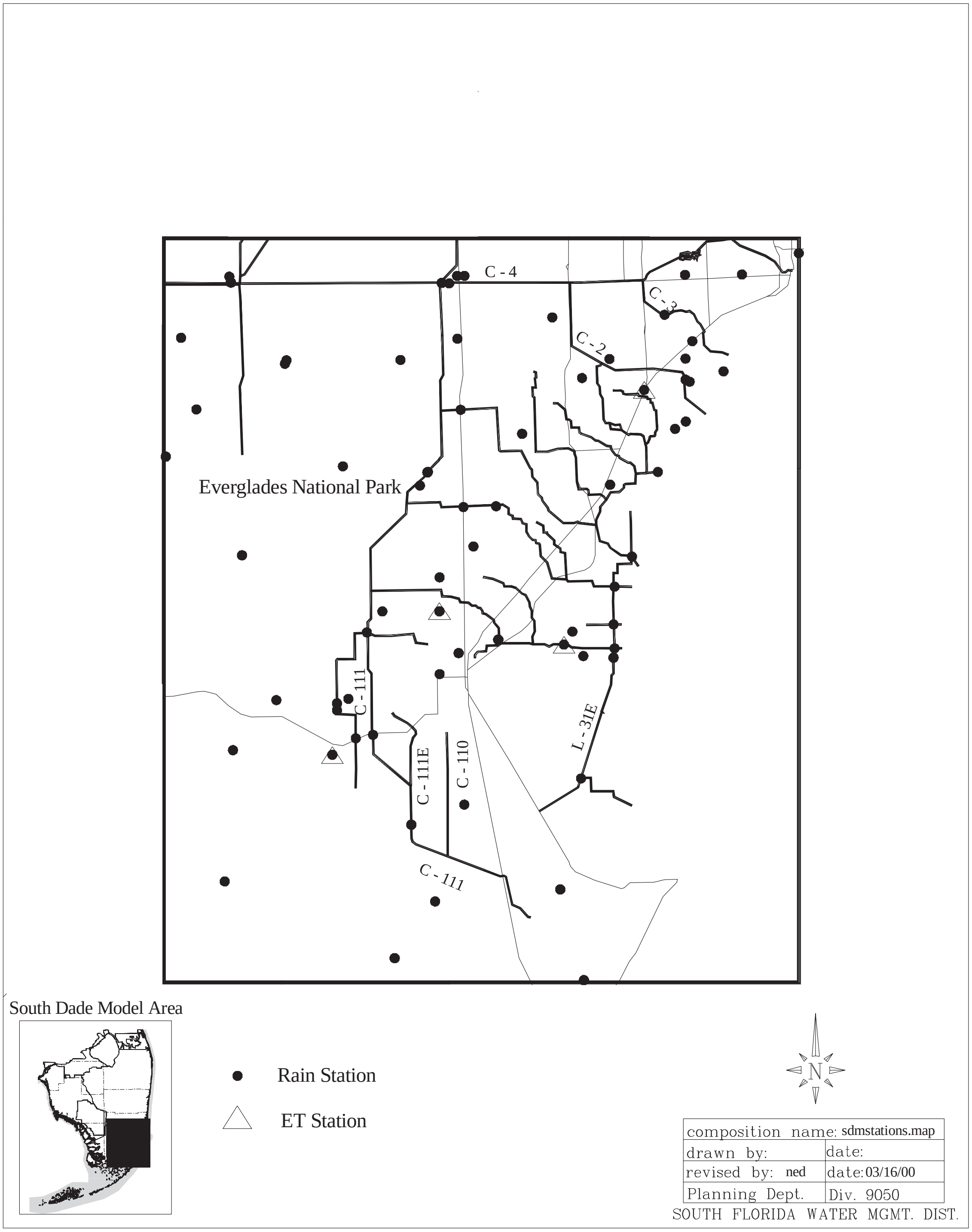

Figure F-13. Rainfall and Evapotranspiration Station Locations used in the South Miami-Dade Ground Water Flow Model.

operated by the Turkey Point power plant. Water levels in all of these canals are controlled and maintained by a network of District and Miami-Dade DERM water control structures.

Canal-aquifer interactions are included in the model through use of the River and Drain packages. Canals were classified as either rivers or drains depending on their physical and operational properties. Most of the canals were classified as rivers. In either case, the required input data included canal stages along with conductance terms depicting the degree of hydraulic interaction between the canals and the aquifer. Canal stages were assigned to the various canal reaches by using measured water levels at stage monitoring stations to estimate hydraulic grade line elevations within each reach.

Wetlands

The major wetland systems within the active model area include large portions of Everglades National Park, the Bird Drive Basin, the Model Lands, and the wetland margins of Biscayne Bay (**Figure F-12**). Ground water levels, structure discharges, rainfall, ET, and topography influence surface water elevations within these wetlands.

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow within the wetland systems along with interactions between the surface water and ground water. Topographic features influencing the rate of movement through the wetlands (i.e. levees, sloughs, and air boat trails) are explicitly represented in the wetlands package.

Water Use

Ground water withdrawals in southern Miami-Dade County are for PWS and golf course, landscape, and agricultural irrigation. The location of these wells are shown in **Figure F-12**. All permitted withdrawals are explicitly represented in the modeling through the Wells package. In addition to permitted users, there are a significant number of unpermitted agricultural irrigators within the south Miami-Dade agricultural area. The demands from these users are represented implicitly through the Evapotranspiration package.

Demands for irrigation users were based on estimated daily potential ET and corresponding supplemental crop requirement. For PWS users, information contained in monthly water use reports submitted to the District was used to assign monthly pumpage rates to each water use permit. The resulting mean daily pumpage for each permit was then divided among its wells according to a specified percentage for each well.

Features of the Outer Boundary

As shown in **Figures F-1** and **F-12**, the portion of the outer model boundary located east of the levees consists of the following:

- A coastal boundary
- A northern boundary located along the C-4 Canal

- A western boundary corresponding the approximate location of the east-west ground water divide depicted in USGS Open-File Report 95-705 (Sonenshein and Koszalka, 1996)

Along the coastal boundary, the required stages and conductance values were determined in the manner explained in the General Subregional Model Features section of this appendix. To represent the wedge-like shape of the saltwater interface (Sonenshein, 1995), the location of the boundary cells move inland in the deeper layers of the model. During model calibration, this boundary was represented as a constant head condition. For planning simulations, the coastal boundary, like all of the other outer boundaries, was incorporated into the model using the General Head Boundary package.

Along the northern boundary, stages were based on water levels in canals while the conductance terms were computed in each model layer using the hydraulic conductivity values and dimensions of the boundary cells.

Along the western boundary, heads were fixed using historical data from wells G-3354 and G-3437. The conductance values for these sections of the model boundary were based on the same information used to compute conductance values along the northern and southern boundaries.

Model Calibration

The period of record selected for history matching was 1988-1989, which had relatively dry hydrologic conditions. Objectives for the history matching were to compare measured and computed water levels at monitoring sites and to adjust model parameters as appropriate to reduce errors to an acceptable level.

Differences between computed and observed water levels are summarized in **Table F-11**. Also provided are mean error, or the bias, and residual standard deviation for each site. In order to minimize any effects of initial conditions on these results, the residuals for the first two months of each period of record were not used in the analysis.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. At some gages, data only exist over a fraction of the total period of record and result in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels. In contrast, the model computes water levels at the end of each time step, which, in this case, is at the end of each day. Additionally, one can generally not expect a finite-difference based model to replicate ground water levels observed in the immediate vicinity of a pumping well due to limitations imposed by the spatial resolution of the model. Finally, it should be emphasized that the calibration results depicted in **Table F-11** reflect the current status of the model and are subject to change as improvements to the model are made.

Table F-11. South Miami-Dade County Calibration Statistics for the Period of Record (1993-94)

Gage Name	Percent of Days: Within Minimum Criterion (+/- 1.0 ft)	Percent of Days: Within Desired Criterion (+/- 0.5 ft)	Mean Error (Bias) (feet)	Standard Deviation (feet)	Notes
G-618	90.96	54.61	-0.390	0.444	
G-3439	61.19	20.00	0.882	0.456	
G-1074B	6.30	3.56	-5.537	2.333	Within Alexander Orr Wellfield Complex
G-3073	78.08	15.98	0.792	0.336	
G-3074	73.52	32.42	0.292	0.831	Located near PWS well within Snapper Creek Complex
G-551	86.73	55.41	0.499	0.444	
G-1487	84.29	42.47	-0.156	0.729	
G-855	91.32	50.50	-0.032	0.623	
G-580A	96.44	73.70	0.316	0.319	
G-580	96.44	73.70	0.316	0.319	
G-553	76.16	33.15	0.710	0.351	
G-858	76.99	45.66	0.620	0.529	
G-596	81.37	48.40	-0.368	0.660	
G-3273	80.27	58.72	-0.218	0.709	
G-860	98.08	67.12	0.294	0.370	
G-1502	82.56	57.08	-0.081	0.702	
G-1362	90.59	64.57	-0.024	0.586	
G-757A	95.43	55.16	-0.184	0.550	
G-3437	85.30	57.17	-0.220	0.616	
G-614	96.89	74.34	-0.215	0.425	
G-1363	95.80	67.58	-0.211	0.484	
G-1486	99.63	75.62	0.172	0.362	
G-789	91.69	66.39	-0.345	0.432	
G-1183	94.43	62.37	0.410	0.376	
G-864	92.15	63.56	0.415	0.422	
G-864A	94.70	73.97	0.292	0.442	
G-3356	72.58	26.96	0.825	0.460	
G-613	97.44	84.38	0.033	0.382	
G-3355	63.63	19.17	0.951	0.563	
G-1251	77.35	56.62	0.552	0.511	
G-3354	54.62	26.90	0.926	0.480	
G-3353	99.52	73.73	0.054	0.406	

Recommendations and Conclusions

Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequete for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s) to undergo more detailed analyses. The locations of such performance measures should be within the evaluation area discussed previously. Furthermore, it is suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

Future Improvements

Certain improvements to the model are recommended in order to enhance its ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

LITERATURE CITED

Causaras, C.R. 1985. *Geologiy of the Surficial Aquifer System, Broward County, Florida*. Water Resources Investigations Report 84-4068, U.S. Geological Survey, 2 sheets.

Causaras, C.R. 1987. *Geology of the Surficial Aquifer System, Dade County, Florida*. Water-Resources Investigations Report 86-4126, U.S. Geological Survey, 240 pp, 3 sheets.

Council, G.W. 1998. A Lake Package for MODFLOW. In EDITORS, *Proceedings for MODFLOW '98*, Colorado School of Mines, CO, October 4-8, 1998, Volume II, pp. 675-682.

Fish, J.F. and M.J. Stewart. 1991. *Hydrogeology of the Surficial Aquifer System, Dade County, Florida*. U.S. Geological Survey Water Resources Investigations Report 86-4126. Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Denver, CO, 50 pp, 11 sheets.

Krupa, A.J. 1997. *Results of Literature Review and Assessment of Geologic Logs to Determine the Extent of the Dense Limestone Layer in the Upper in the Upper Portion of the Biscayne Aquifer in the Pennsuco Area, Dade County.* Draft Memorandum, Planning Department, South Florida Water Management District, West Palm Beach, FL, 27 pp.

Lal, A.M.W. In press. Selection of Spatial and Temporal Discretization of Ground Water and Overland Flow Models. *Water Resources Research*.

Nair, S.K. and M.M. Wilsnack. 1998. A Comparison of Two Approaches for Simulating Lake-Ground Water Interactions with MODFLOW. In EDITORS *Proceedings for MODFLOW '98,* Colorado School of Mines, CO, October 4-8, 1998, Volume II, pp. 871-878.

McDonald, M.G. and A.W. Harbaugh. 1988. A Modular, Three-Dimensional Finite-Difference Ground Water Flow Model. *Techniques of Water Resources Investigations of the United States Geological Survey, Book 6*. U.S. Government Printing Office, Washington, D.C.

Perkins. 1977. Depositional Framework of Pleistocene Rocks in South Florida. In: Enos, P. and Perkins, R.D, *Quaternary Sedimentation in South Florida*, Geological Society of America Memoir 147: 131-196.

Restrepo, J., Bevier, C., and Butler, D. 1992. *A Three-dimensional Finite Difference Ground Water Flow Model of the Surficial Aquifer System, Broward County, Florida*. Technical Publication 92-05, South Florida Water Management District, West Palm Beach, FL.

Restrepo, J.I. and J.B. Giddings. 1994. Physical Based Methods to Estimate ET and Recharge Rates Using GIS. In: *Effects of Human-Induced Changes on Hydrologic Systems,* American Water Resources Association, Bethesda, Maryland.

Restrepo, J.I. and A.M Montoya. 1997. *MODFLOW Wetland Module: Final Report*. Department of Geography and Geology, Florida Atlantic University, Boca Raton, FL, 86 pp.

Restrepo, J.I., A.M. Montoya, and J. Obeysekera. 1998. A Wetland Simulation Module for the MODFLOW Ground Water Model. *Ground Water,* Vol. 36, No. 5, September-October, 1998, pp. 764-770.

Klein H. and C.B. Sherwood 1961. *Hydrologic Conditions in the Vicinity of Levee 30, Northern Dade County, Florida*. Report of Investigations No. 24, Part I, Florida Geological Survey, Tallahassee, FL, 24 pp.

Shine, M.J., D.G.J. Padgett, and W.M. Barfknecht. 1989. *Ground Water Resource Assessment of Eastern Palm Beach County, Florida*. Technical Publication 89-4, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1993. *Draft Working Document Lower East Coast Regional Water Supply Plan*. Planning Department, South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1996. *Northwest Dade County Freshwater Lake Plan.* South Florida Water Management District, West Palm Beach, FL.

Smajstrla, A.G. 1990. *Technical Manual for the Agricultural Field Scale Irrigation Requirements Simulation Model, Version 5.5*. Agricultural Engineering Department, University of Florida, Gainesville, FL.

Sonenshein, R.S. 1995. *Delineation and Extent of Saltwater Intrusion in the Biscayne Aquifer, Eastern Dade County, Florida*. Water-Resources Investigations Report 96-4285, U.S. Geological Survey, 1 sheet.

Sonenshein, R.S. and E.J. Koszalka. 1996. *Trends in Water-table Altitude (1984-93) and Saltwater Intrusion (1974-93) in the Biscayne Aquifer, Dade County, Florida*. Open-File Report 95-705, U.S. Geological Survey, 2 sheets.

Swayze, L.J., and W.L. Miller. 1984. *Hydrogeology of a Zone of Secondary Permeability in the Surficial Aquifer of Eastern Palm Beach County, Florida*. USGS Water Resources Investigations Report 83-4249, Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Denver, CO.

Wilsnack, M.M. 1995. The Use of ARC/INFO and MODFLOW to Evaluate the Feasibility of Using Limestone Mining Quarries in Southern Florida as Ground Water Recharge Basins. In EDITORS, *Proceedings of the Seventh Biennial Symposium on the Artificial Recharge of Ground Water: the Role of Recharge in Integrated Water Management*. Tempe, AZ, pp. 199-213.

Wilsnack, M.M. and S.K. Nair. 1998. Designing an ARC/INFO Database for a MODFLOW Model: a Case Study in the Limestone Mining Belt of Southern Florida. In EDITORS, *Proceedings for MODFLOW '98*. Colorado School of Mines, CO, October 4-8, 1998, Volume II, pp. 649-656.

Wilsnack, M.M., S.K. Nair, and J. Obeysekera. 1997. *Hydrologic Modeling of Initial Lake Belt Alternative Configurations: Ground Water Modeling*. Hydrologic Systems Modeling Division, South Florida Water Management District, West Palm Beach, FL, 66 pp.

Yan, J.J., C. Bevier, and K.A. Smith, 1995. *Revision and Recalibration of the Three-Dimensional Ground Water Model of Palm Beach County, Florida*. Technical Publication DRE 322, South Florida Water Management District, West Palm Beach, FL.